INDIRECT MEASUREMENT OF
CROP PLANT HEIGHT

By

PAMELA LYNN TURNER

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CROP PLANT HEIGHT

Thesis Approved:

Dr. William Raun

Thesis Advisor

Dr. John Solie

Dr. Randy Taylor

Dr. A. Gordon Emslie

Dean of the Graduate College

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

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CHAPTER I

ABSTRACT

Expressed variation within production agriculture fields changes from year to year. Fast, real time, and inexpensive methods in precision agriculture are being developed to account for in-field variation in crop management systems. Research has found that Normalized Difference Vegetation Index (NDVI) times height is a good predictor of forage yields and N uptake. This study was initiated to establish the relationship between plant height measured by hand and using a calibrated sonar device. A total of 50 in-field observations were taken at several growth stages for corn (*Zea Mays* L.), cotton (*Gossypium hirsutum* L.), sorghum (*Sorghum bicolor* L.), and winter wheat (*Triticum aestivum* L.) in Stillwater, OK from 2006 to 2007. Height measurements were determined by hand readings taken with a ruler and sonar readings taken with a MassaSonic M500/95. Hand and sonar height measurements were regressed to determine the coefficient of determination (r^2). In 2006, data collected from 23 to 73 days after planting (DAP) showed that 95% of the variation in actual cotton height could be explained by the sonar readings. The r^2 obtained from hand and sonar heights were 0.81 and 0.42 for winter wheat (128 to 151 DAP) and for sorghum (22 to 72 DAP), respectively. Establishing the relationship between hand and sonar measurements is essential to include plant height in "on the go" predictions of forage biomass and N fertilizer rate requirements.

CHAPTER II

REVIEW OF LITERATURE

Yields obtained from crop fields can vary from season to season for a variety of reasons. Precision agriculture can account for in-field variability and manage inputs on a site-specific basis. One of the biggest management concerns is the uniformity of crop stand. Martin et al. (2005) stated that a 2-leaf growth stage difference can result in delayed emergence ranging from 5-10 days, which can cause a 2% yield loss for each 1-day delay. Therefore a producer's goal should be to eliminate by-plant variability by developing production management systems that homogenize plant stands, and emergence, thus decreasing plant-to-plant variation. Research on plant spacing variability indicated that about 2.5 bu/ac of grain yield is lost for every inch increase in the standard deviation of the plant-to-plant spacing (Nafziger et al., 1993). This variability can make it difficult to determine nutrient needs accurately. Raun et al. (1986) showed that corn seedlings which emerge late essentially become weeds competing for nutrients and water. Therefore, there is a need to develop a remote sensor that can detect physical characteristics, such as height, to help adjust in-field variability.

Several methods have been introduced to increase a producer's knowledge of what is happening in the field and different strategies to obtain better uniformity. One technique is the use of remote sensing. Remote sensing is the act of detection and identification of an object, or landscape without having a sensor in direct contact with the object (Ess and Morgan, 2003). It is involved with many components in studying supply and demand for agriculture products which has led to the development of precision farming. An essential element of precision farming is the use of variable rate technology (VRT) (Lillesand et al.). By combining remote sensing with plant height in this project, management practices could be improved for “on-the-go” VRT applications. Research, with ultrasonic sensors (Model M-5000/95, Massa Products) on plant height, investigated echo signals from corn plant canopies to determine leaf height estimation and the interaction between leaf surfaces and ultrasonic signals. Determining the leaf height was accomplished by detecting echo peaks from ultrasonic scans which were converted into an estimated height and then plotted against the scan number. This procedure could then estimate plant growth stage. The interaction between leaf surfaces and ultrasonic signals found good correlation for 18 plants with r^2=0.56 (Aziz et al., 2004). In previous studies, Kataoka et al. (2002) concluded that an ultrasonic sensor preformed better for soybean and corn height measurements than a laser beam sensor. Sui et al. (1989) developed a method to provide estimates of cumulative plant volume and maximum and average plant width and height. This was accomplished by a microcomputer-based measurement system using ultrasonic modules in bush-type plants such as cotton and soybean fields. Alexandre Cândido Xavier et al. (2006) presented the highest R^2 values to estimate both grain yield at booting and heading stages (R^2 = 0.74) and plant height at heading stage (R^2 = 0.68) by using the optimum multiple narrow-band reflectivity (OMNBR) with four bands. By using an existing two-layer model for forest height estimation, Ballester-Berman et al (2004) reformulate the model to develop an algorithm based on polarimetric SAR interferometry in corn crops.

Determining a non-destructive measurement of height is important in order to associate that data with other parameters. Read (2003) stated that plant height, leaf area index, and lint yield were associated with NDVI (normalized difference vegetative index) maps and with NIR (near infrared) band values acquired from aircraft of handheld sensors in cotton. He then concluded that this could offer important mid-season management for site specific farming, especially for dryland cotton. Freeman et al. (2006) reported that by knowing the plant height and NDVI, corn crop biomass can be better determined than when using NDVI alone. If the biomass can be predicted, then silage and final grain yield can be estimated. By predicting the grain yield, N rates for mid-season application can be determined more accurately on a by-plant basis (Freeman, 2006), therefore, increasing nitrogen use efficiency (NUE). Raun and Johnson (1999) estimated NUE for world cereal grain production systems is approximately 33%.

The objectives of this study are to establish height with a MassaSonic ultrasonic sensor for corn, cotton, wheat, and sorghum. By determining the relationship between physical and sensor readings, subsequent work can use estimated height as an input for other processes. This will be beneficial in a field setting for producers to use this data as a bench mark for each crop or target. These crops are important to evaluate for variety of reasons. Once the relationship is established, the readings for plant height can be used with NDVI to determine yield potential and mid-season N application rates more accurate.

CHAPTER III

METHODOLOGY

Two years (2006 and 2007) of data were collected to establish the relationship between height measurements collected by hand and a calibrated MassaSonic ultrasonic sensor. Corn was measured at stages V8, V10 and VT (Hanway and Ritchie, 1984) between June and July. Site readings were taken at Perkins' Research Station, Perkins, Oklahoma and Lake Carl Blackwell, west of Stillwater, Oklahoma. Sorghum and cotton were measured at 1 week intervals during the months of June and July. Cotton and sorghum measurements were also taken at the irrigated experiment station at Lake Carl Blackwell, near Stillwater, Oklahoma. Wheat was measured at Feekes (Large, 1954) growth stages 5, 7, and 10 which is the equivalent to Zadoks scale 30, 32, and 45, (Zadok, 1974) respectively, during the months of February, March, and April. For wheat, one location was established at the Oklahoma State University Agronomy Farm, Stillwater, Oklahoma. Sensor and hand measurements were taken up to 70 cm above the plant. Samples were taken at random from each crop every time a plant is measured.

The height of the sensor (base of sensor to the ground) was first measured before taking any readings to obtain a base height. Measuring the space between the base of the sensor to the top of the canopy followed. After taking the measurement by hand, the reading, in mAmps, from the sensor was taken. Next, the mAmps reading was converted into centimeters in Microsoft Office Excel using the following equation;

Plant height = (3.7809 * voltage reading -3.1698) * 2.54

This number and the physical measurement were then subtracted from the base height of the sensor to get the total height of the plant. Next, the total height of the plant taken with the sensor and measured physically was graphed on an XY scatter chart. After the data points were graphed, a trendline, equation, and r^2 were added to illustrate the relationship.

To test the differences between slopes and intercept components from two independent regressions, Statistical Analysis System (SAS) 9.1.3 was used. The sets of data that were tested together were 2006 and 2007 sorghum, 2006 and 2007 cotton, and 2007 sorghum and corn.

The sensor used was an ultrasonic M-5000/95 from MassaSonic Company (Hingham, MA). The system beam angle is given at a conical reading of 8^o. The narrow beams transmit sound waves which then process the return echo. The returned echoes then produce outputs at 20 mA (http://www.disensors.com/HTML/pdf/M5000_95.pdf). These can then in turn be calibrated to decipher distance.

CHAPTER IV

RESULTS

The linear relationship between plant height measured by hand and height estimated using the sonar is reported for all growth stages and crops. Analysis was partitioned by year since response functions varied in differing environments.

<u>Wheat</u>

2007

At Feekes growth stage 4 (stem elongation begins and most tillers formed), the linear relationship between measured height and sonar resulted in an r^2 of 0.72. (Figure 1). This same relationship plotted at Feekes growth stage F5 (leaf sheaths strongly erect) resulted in an r^2 of 0.83 (Figure 2). At Feekes growth stage F6 (first node visible on main stem), the linear regression had an r^2 of 0.73 (Figure 3). The final wheat measurement at Feekes growth stage 10 (head developed and can be seen in the swollen sheath) resulted in r^2 of 0.76 (Figure 4).

When analyzed over all growth stags and sites, the linear regression of measured height on sonar estimated height had an r^2 of 0.81 (Figure 5). There were some differences in the linear equations between growth stages, but when combined, a distinct trend was evident (Figure 5). Especially when wheat was shorter (< 30 cm), distinct differences were noted between the growth stages (Figure 5.). This may have been due to morphological differences or possibly faulty calibrations.

Corn

2007

At the six leaf growth stage (V6) in corn, an r^2 of 0.69 resulted from the linear equation between sonar and measured height (Figure 6). At the seven leaf (V7) growth stage the linear relationship between measured height and sonar height had an r^2 relationship of 0.86 (Figure 7). By the nine leaf (V9) growth stage a linear relationship between height estimated using sonar and that measured by hand and had an r^2 of 0.58 (Figure 8). The decrease in r^2 with advancing stage of growth was to some extent expected since the data range (height) is narrowed as the crop progresses.

When combined over sites and stages of growth, sonar measurements explained 92 % of the variation in measured height in corn (Figure 9). Results in Figure 9 were encouraging since small differences in linear relationships were noted between stages of growth. The trend for decreased correlation with time was similar to the work done by Aziz et al. in 2004 where they took measurements at the V6 and V9 growth stages. At V6 growth stage, 87% of the variation in hand measurements was explained by the sonar while the V9 growth stage resulted in decreased correlation with only 41% of the variation explained. This trend in corn is plausible considering the increased size of the corn leaf with advancing growth and increased variability in surface height (top of the leaf to the top of the stalk). As the corn plant grew, the increased angle of the leaf made it more difficult to measure the specific location on the leaf therefore causing the correlation to decrease.

Cotton

2006

For the first year measurements in cotton, a linear relationship was observed at growth stage 3 (main stem elongation with 10% crop cover closure) (Munger et al. 1998) and that resulted in an r^2 of 0.73 (Figure 10). At growth stage 5 (inflorescence emergence and first floral buds detected), the relationship between sonar and measured height had an r^2 of 0.82 (Figure 11). Two sets of readings were taken at growth stage 6 (flowering; first flowers open). The first set, taken at "early bloom" (beginning of flowering), resulted in a linear relationship with an r^2 of 0.90 (Figure 12) and the second set, taken at "late bloom" (finishing flowering), resulted in an r^2 of 0.81 (Figure 13). Growth stage 7 (development of fruits and seeds) also had two sets of readings taken. The first, taken when 20% of the bolls had attained their final size, had a linear relationship and an r^2 of 0.89 (Figure 14). The second set of measurements taken when 60% of the bolls had attained their final size, concluded with a relationship of 0.93 (Figure 15).

2007

For the first measured growth stage in 2007, growth stage 1 (leaf development), the relationship between the sonar and measured height resulted in an r^2 of 0.82 (Figure 16). At growth stage 3 (main stem elongation with 10% crop cover closure), a linear relationship was observed with an r^2 of 0.85 (Figure 17). At growth stage 5 (inflorescence emergence and first floral buds detected), two sets of measurements were taken. The linear relationship between measured and sonar height for the first set (20% of crop's floral buds detected), taken when first floral buds were detectable, had an r^2 of 0.89 (Figure 18) and an r^2 of 0.96 (Figure 19) for the second set (80 % of crop's floral buds developed). At the last measured growth stage, 7, the liner model resulted in an r^2 of 0.93 (Figure 20).

When analyzed over all stages of growth at one site in 2006, the linear relationship resulted in an r^2 of 0.95 (Figure 21). When analyzing data from 2007, a linear relationship resulted in an r^2 of 0.99 (Figure 22). The 2006 and 2007 data were combined for two different graphs; the first to demonstrate the correlation and linear equation and second to demonstrate the difference in the two linear models' slopes and intercepts. Combining the two years together resulted in an r^2 of 0.97 from the linear model (Figure 23). Years 2006 and 2007 were combined following analysis that showed no difference in slope and intercepts between the independent year equations at the 5% level (Figure 24).

Sorghum

2006

For the first measured readings, at growth stage 3 (growing point differentiation; vegetation changes to reproduction), a linear relationship between sonar and measured height expressed an r^2 of 0.47 (Figure 25). At growth stage 4 (final leaf in whorl visible; 80% of total leaf area potential), the linear regression resulted in an r^2 of 0.52 (Figure 26). At the next measured growth stage, growth stage 5 (boot; all leaves fully expanded), a linear regression was noted with an r^2 of 0.68 (Figure 27). For growth stage 6 (half bloom; half of plants in a field are in some stage of bloom), the linear regression resulted with an r^2 of 0.26 (Figure 28). At the final measured growth stage in 2006, growth stage 7 (soft dough; grain has dough-like consistency) linear regression resulted in an r^2 of 0.45 (Figure 29).

2007

The first measured growth stage in 2007, growth stage 3 (growing point differentiation; vegetation changes to reproduction), a linear regression resulted in an r^2

of 0.45 (Figure 30). At stage, 5 (boot; all leaves fully expanded), a linear regression had an r^2 of 0.52 (Figure 31). The final measurements taken in 2007 were at growth stages 5 and 6 (approximately 80% of crop in boot and 20% in half bloom). For this sampling, the linear relationship between measured and sonar height resulted in an r^2 of 0.37 (Figure 32).

Analyzed over all growth stages for one site in 2006, the linear relationship resulted in an r^2 of 0.42 (Figure 33). When analyzing the 2007 data at two sites, the linear relationship resulted in an r^2 of 0.79 (Figure 34). Years 2006 and 2007 were not combined into a single model because slope and intercept components were significantly different from each other. The reason for such differences in the linear relationship may have been due to the methods used to collect the data. In 2006, readings for the hand measurements were taken by placing the ruler directly in alignment with the sonar. After considering the fact that the sonar is emitting sound waves at an angle, 2007 measured readings were taken two inches away from the center of the sonar. Since the morphological structure of sorghum's leaf grows at an angle, this caused the readings' location to be farther up on the plant. Other reasons for differences in correlation could be the changing morphological characteristics over the entire cycle. In 2006, correlation improved from growth stages 3 to 5. There was a significant decrease in correlation after growth stage 6 and 7 which may have been due to the morphological changes in leaf structure. As the leaf matures, the youngest leaf is more difficult to gather readings, especially with the grain head developing. In 2007, correlation for stages 5 and 6 were significant but as grain heads developed, a decrease in the linear relationship was noted. Years 2006 and 2007, sorghum data was not combined since analysis showed significant differences in slope and intercepts, from two independent regression equations (Figure 35). Analysis for 2007 sorghum and corn was also analyzed to test for differences in regression equations due to the crops' similar morphological characteristics. While testing for differences, only 2007 sorghum data was analyzed because the method used to obtain the information was the same as in corn. The analysis resulted in a significant difference in slope at the 0.01% level. The intercepts also showed a significant difference at < 0.01% from two independent regression equations (Figure 36).

CHAPTER V

DISCUSSION AND CONCLUSION

This experiment's objective was to determine if plant height measured by hand could be measured indirectly using sonar at various growing stages and in different environments. Results showed that, at all stages of growth in cotton, strong correlation was present for both years of data. Due to cotton's morphological characteristics, determining where the sonar's sound waves hit the plant could accurately be predicted. As the crop grows, it has a flatter surface on the upper part of the plant as compared to the other crops investigated in this study. This makes determining the location of where the sonar's sound waves meet the plant uncomplicated since a measurement could be taken from a wide surface angle and different height from the plant to the sonar would always be the same. Hand measurements in wheat also could be accurately predicted at earlier growth stages using sonar. As the wheat plant matured, the morphology of the canopy began to change therefore making it more difficult to accurately measure plant height using sonar. As the wheat plant matured into stems, the angle of the sonar made it difficult to capture a fixed location within the wheat heads. At earlier growth stages the wheat plant has a tighter canopy, making the target location of where the sonar's sound waves easier to determine as in cotton. Although corn did not show a strong correlation by individual growth stages alone, analyzing all stages together was highly correlated. As the plotted growth stages showed, the regression line fit more accurately therefore giving a higher correlation. Corn was easier to measure due to the crop's canopy morphological features. Since corn's leaves do not begin to lie at an angle until V7, the measurements could be accurately predicted later in the growth cycle. Results for sorghum were more inconsistent throughout the growth cycle. One issue with sorghum was the morphological characteristic of the leaf. Sorghum's leaves begin to lie over at a wider angle, compared to that of corn, even at earlier growth stages. Estimating the exact point on the leaf to measure with the sonar was difficult to determine due to the fact that the sonar was giving sound waves off at an angle onto a leaf that was growing at an angle. The first year data in 2006 for sorghum were less correlated due to taking measurements at the wrong location on the leaf. The fact that the sonar was emitting sound waves in a conical shape was not taken into consideration until 2007. Therefore, the measurements taken in 2006 were all approximately two inches from its desired location.

By establishing the relationship between hand and sonar measurements among wheat, corn, cotton, and sorghum, an "on the go" predictor of forage biomass and N fertilizer rate requirements can be created.

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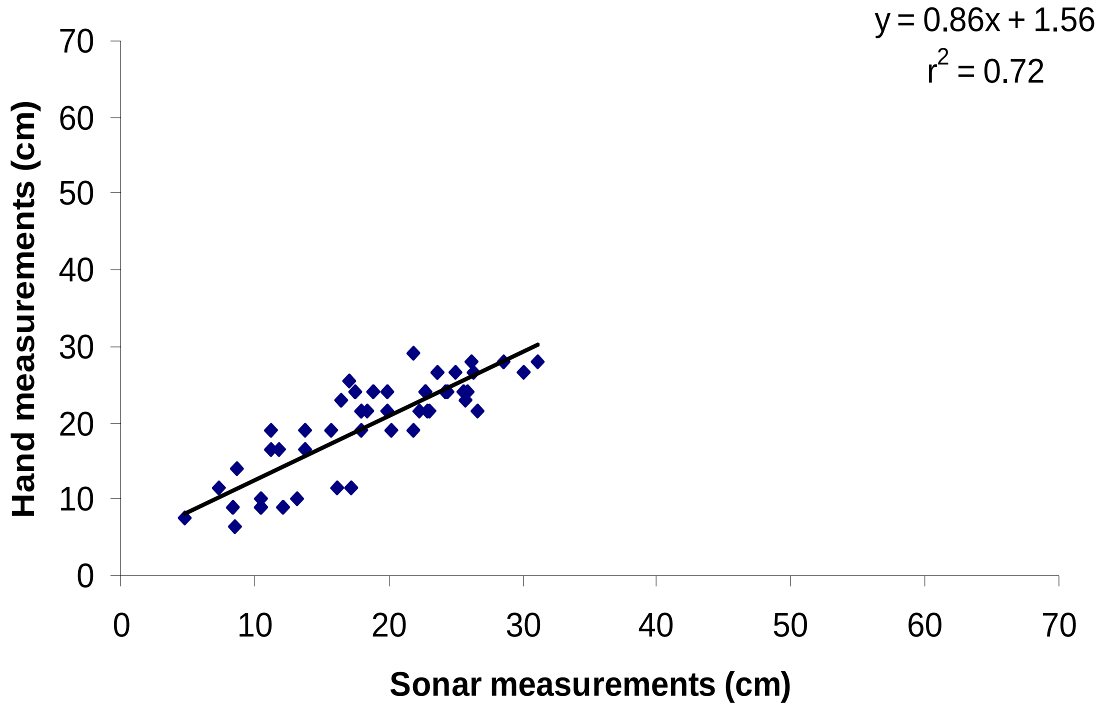

Figure 1. Relationship between measured plant height and that estimated using sonar, 0 to 147 days after planting in wheat, Feekes growth stage 4.

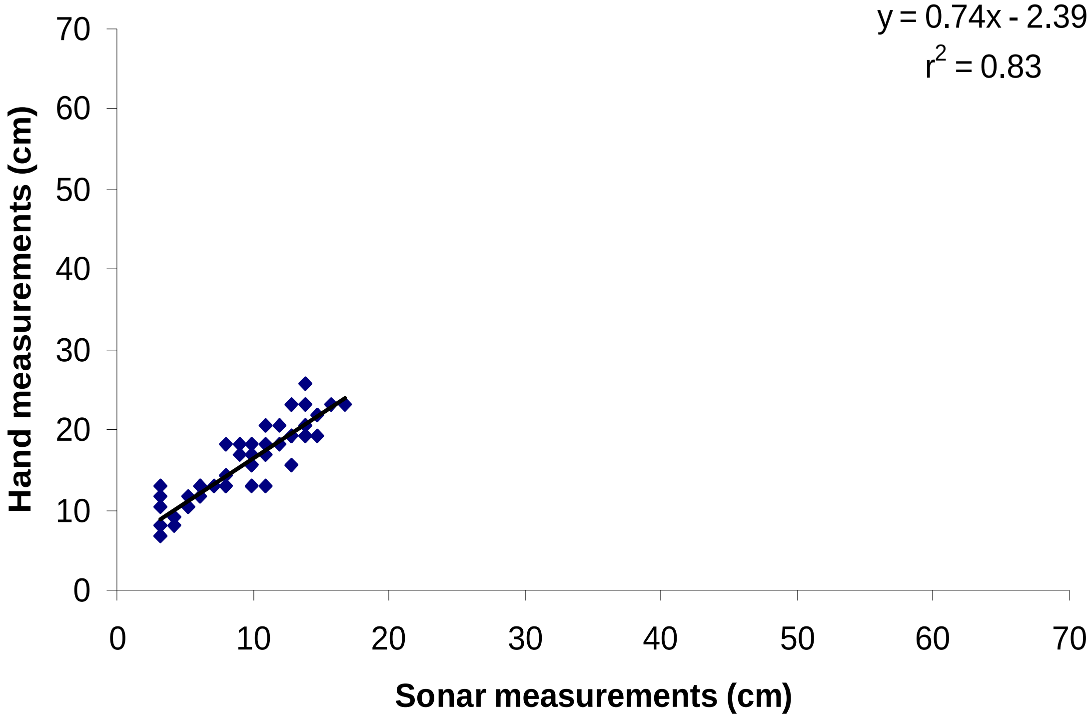

Figure 2. Relationship between measured plant height and that estimated using sonar, 0 to 129 days after planting in wheat, Feekes growth stage 5.

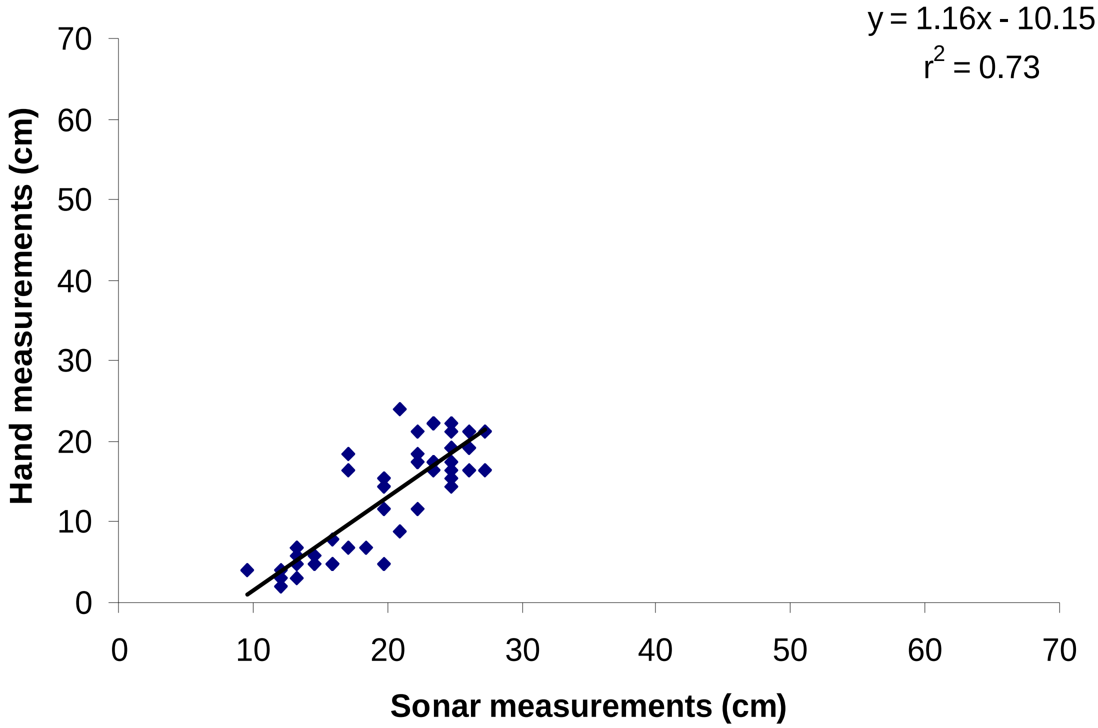

Figure 3. Relationship between measured plant height and that estimated using sonar, 0 to 168 days after planting in wheat, Feekes growth stage 6.

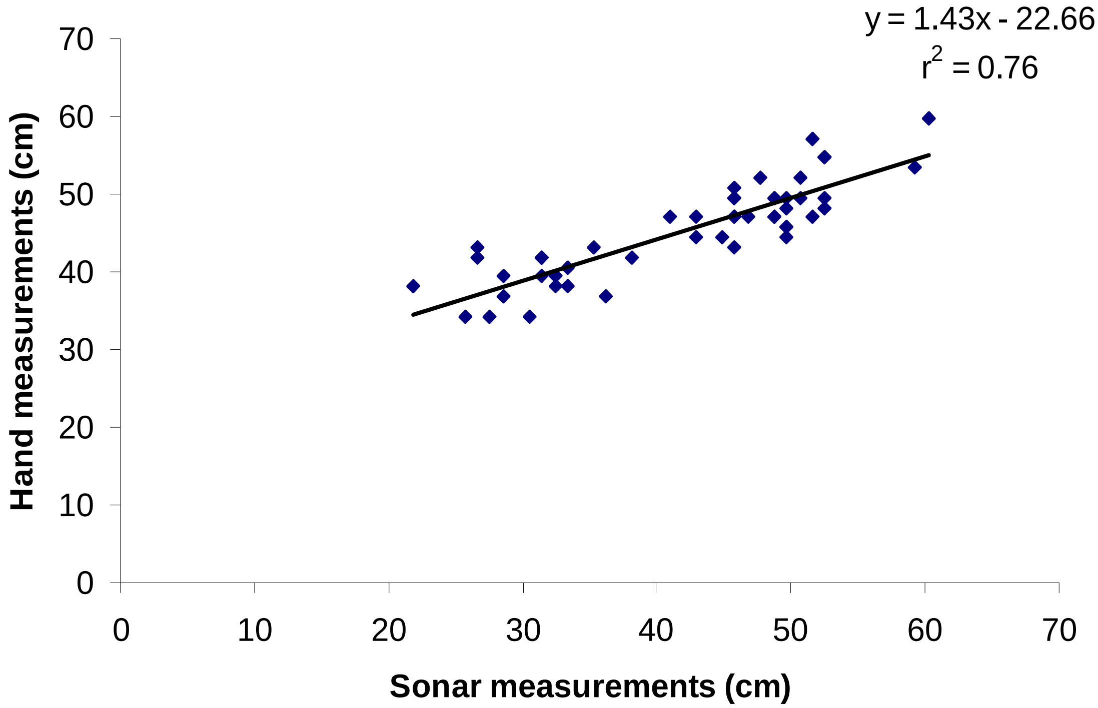

Figure 4. Relationship between measured plant height and that estimated using sonar, 0 to 183 days after planting in wheat, Feekes growth stage 10.

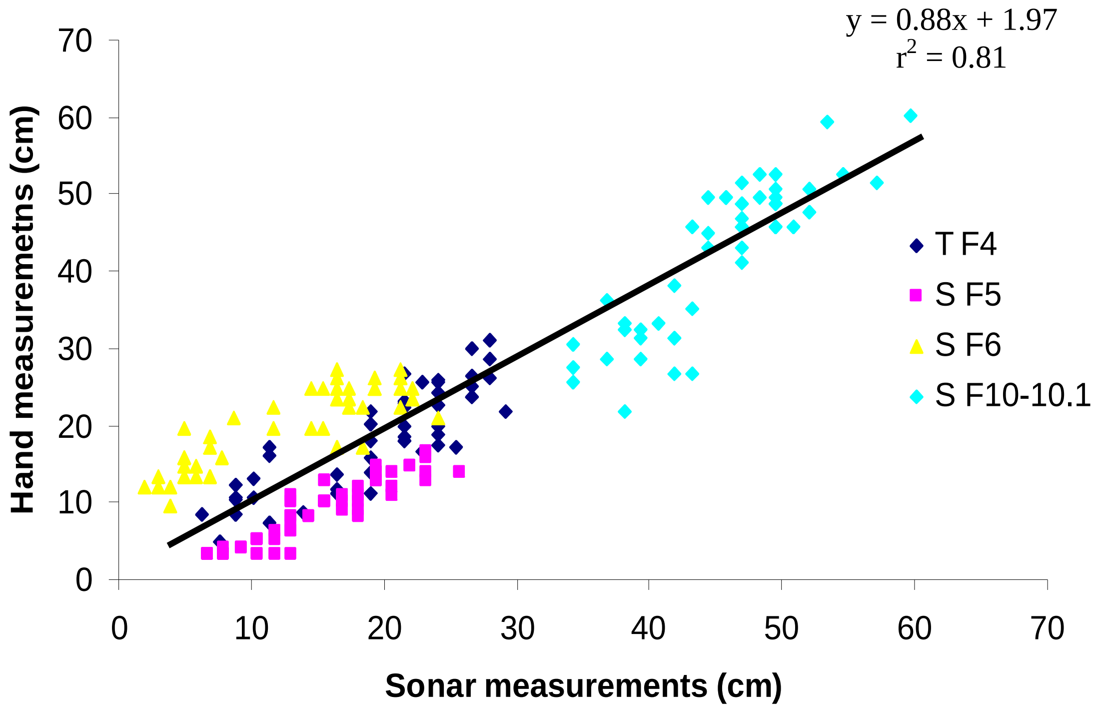

Figure 5. Relationship between measured plant height and that estimated using sonar, 0 to 183 days after planting in wheat including all growth stages at two different locations (T: Teaching Demo, S: Stillwater 222).

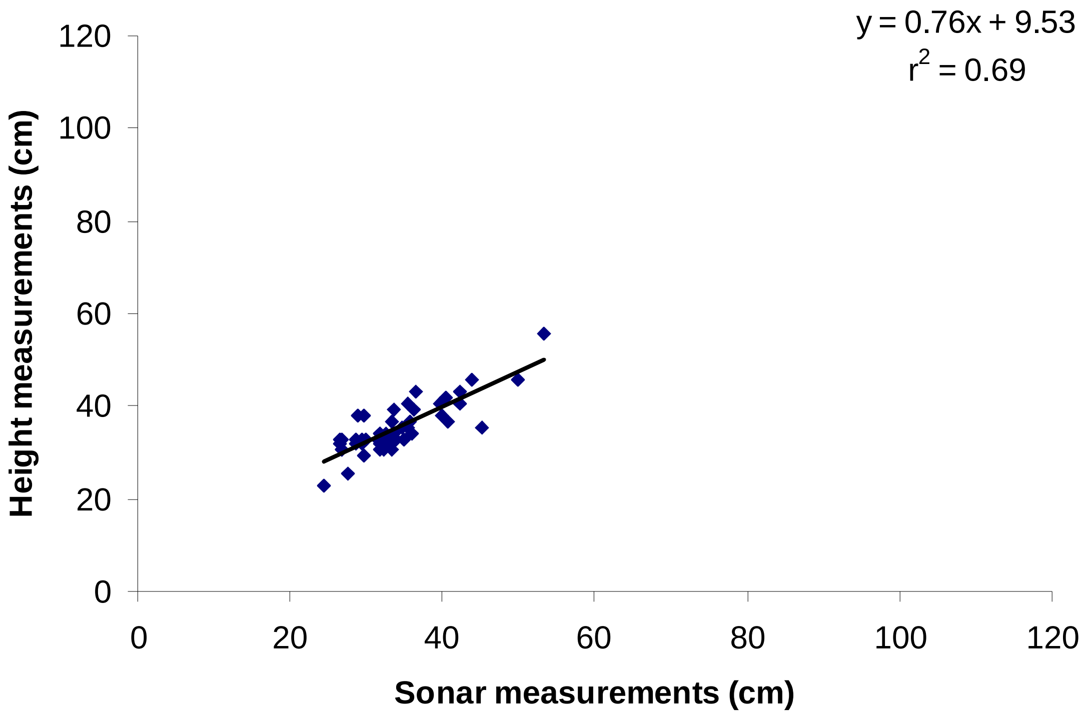

Figure 6. Relationship between measured plant height and that estimated using sonar, 0 to 33 days after planting in corn, V6 growth stage.

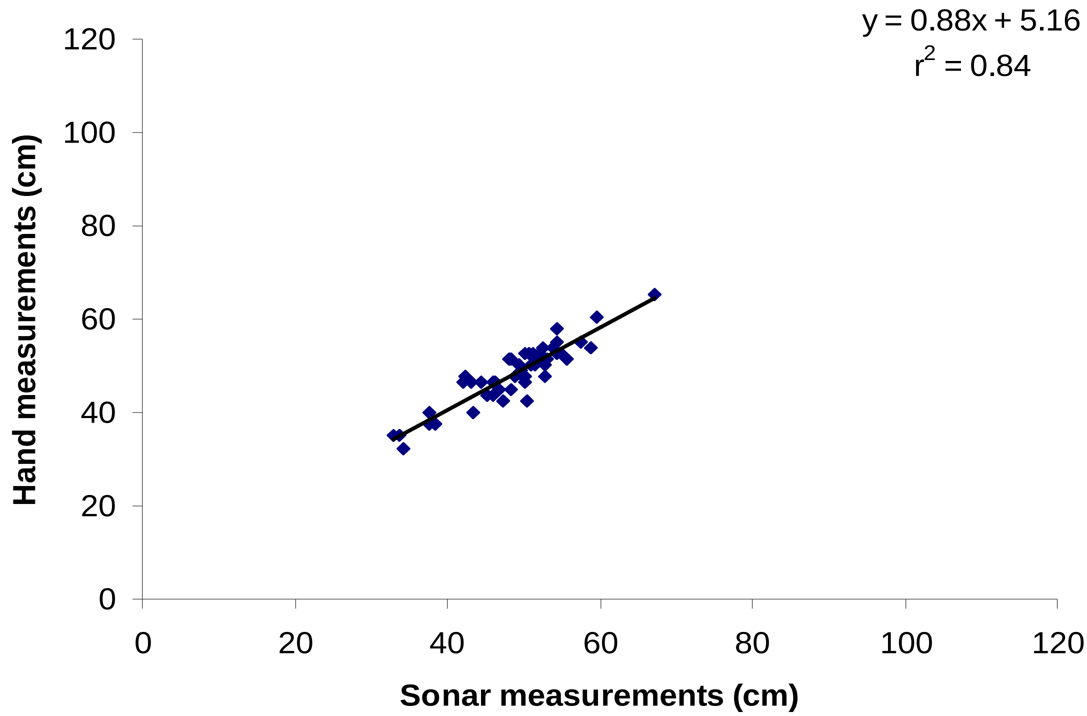

Figure 7. Relationship between measured plant height and that estimated using sonar, 0 to 40 days after planting in corn, V6-V7 growth stage.

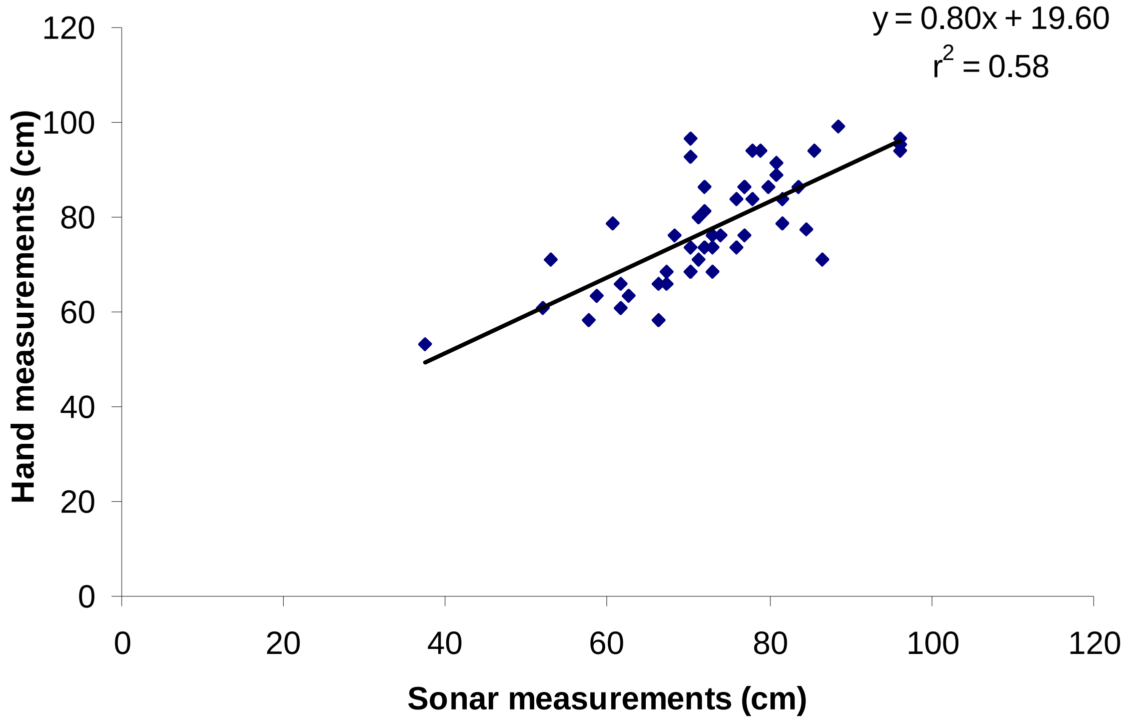

Figure 8. Relationship between measured plant height and that estimated using sonar, 0 to 57 days after planting in corn, V9 growth stage.

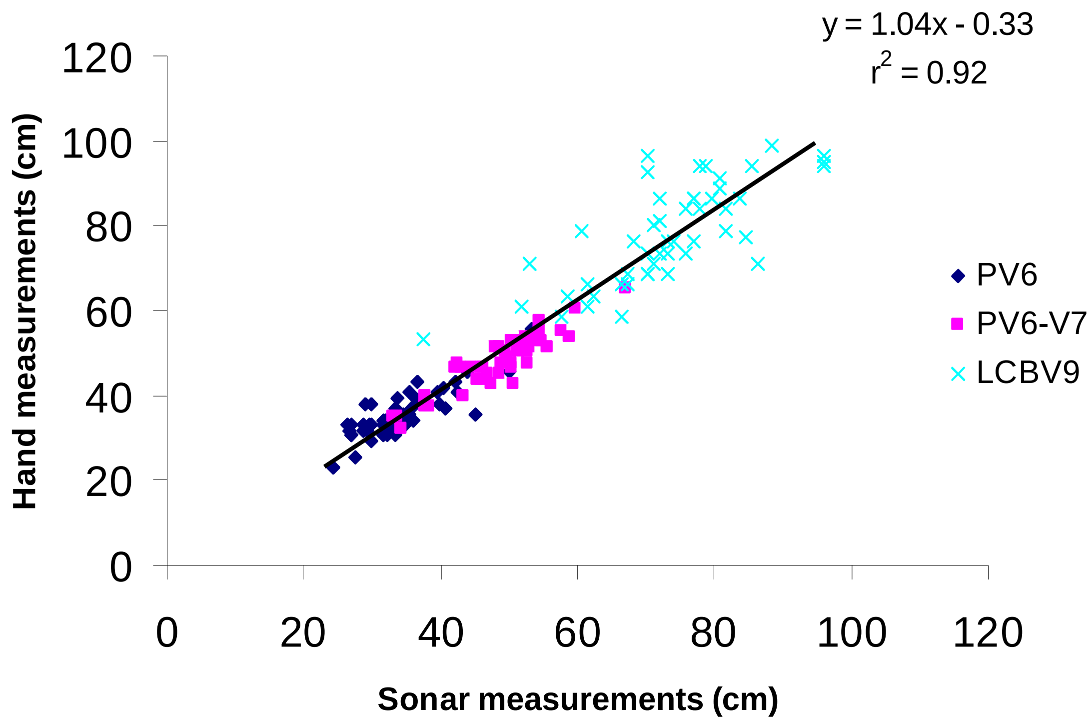

Figure 9. Relationship between measured plant height and that estimated using sonar, 0 to 57 days after planting in corn, including all growth stages at two locations (P: Perkins, LCB: Lake Carl Blackwell).

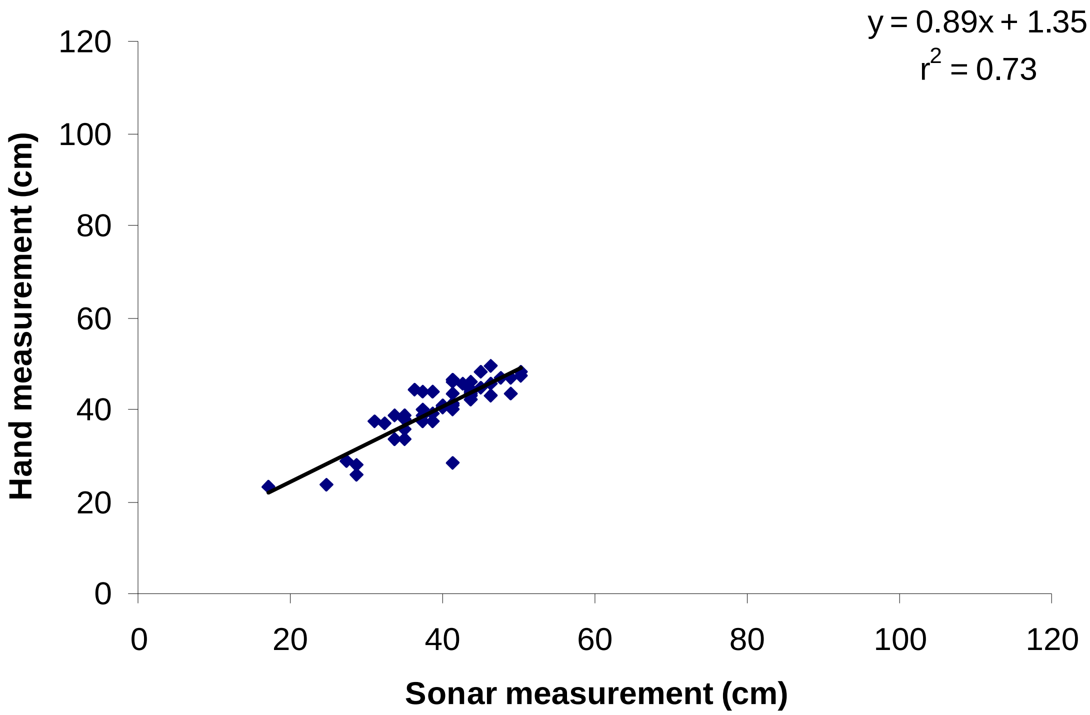

Figure 10. Relationship between measured plant height and that estimated using sonar, 0 to 43 days after planting in cotton in 2006 at growth stage 3.

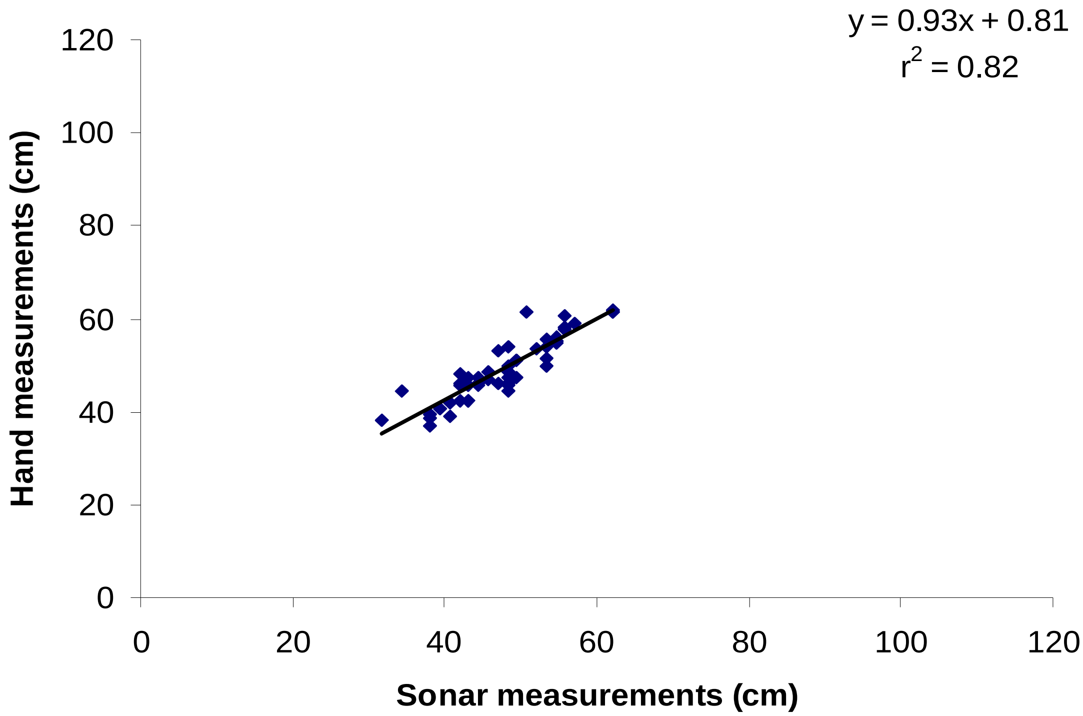

Figure 11. Relationship between measured plant height and that estimated using sonar, 0 to 53 days after planting in cotton in 2006 at growth stage 5.

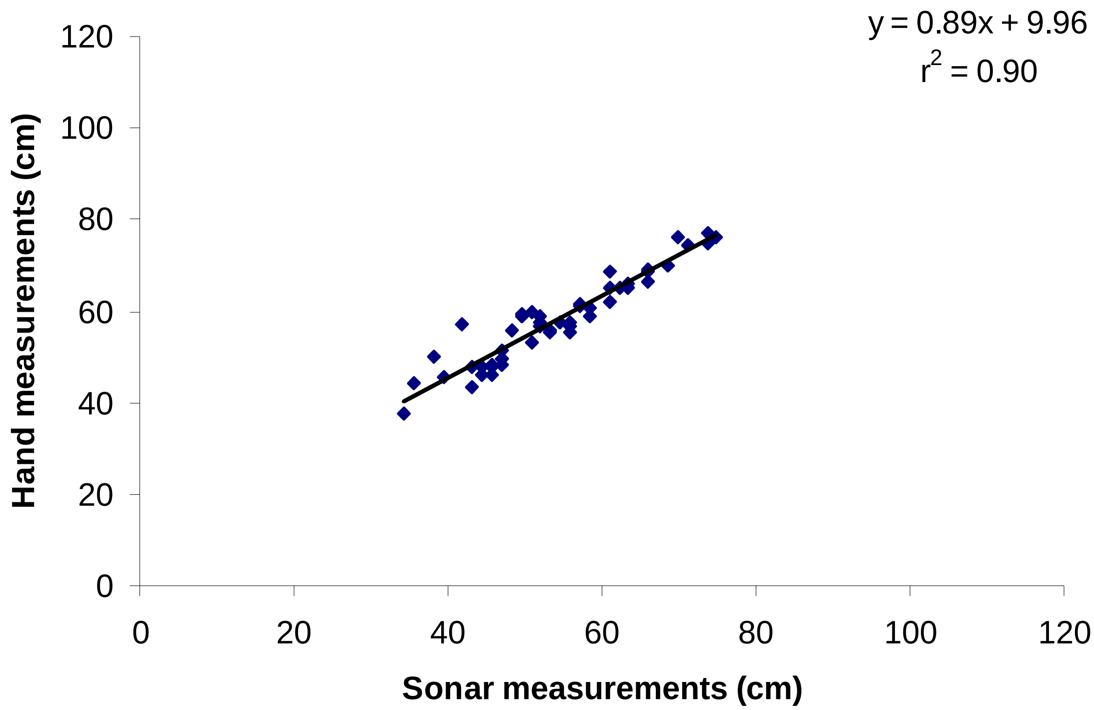

Figure 12. Relationship between measured plant height and that estimated using sonar, 0 to 60 days after planting in cotton in 2006 at growth stage 6.

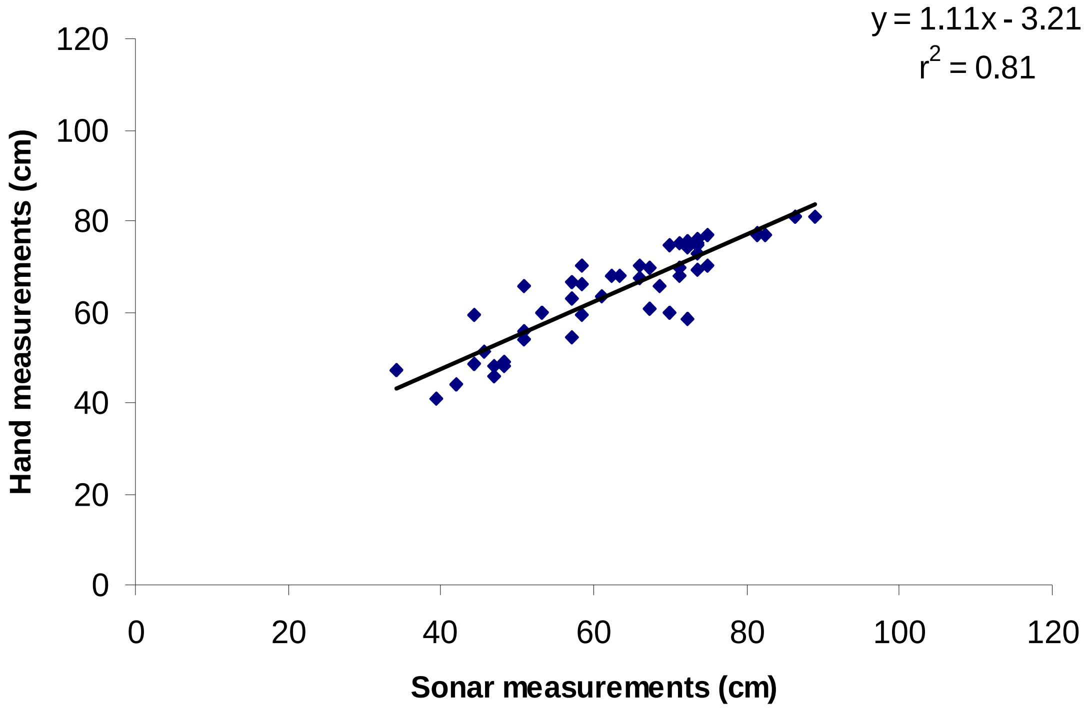

Figure 13. Relationship between measured plant height and that estimated using sonar, 0 to 64 days after planting in cotton in 2006 at growth stage 6.

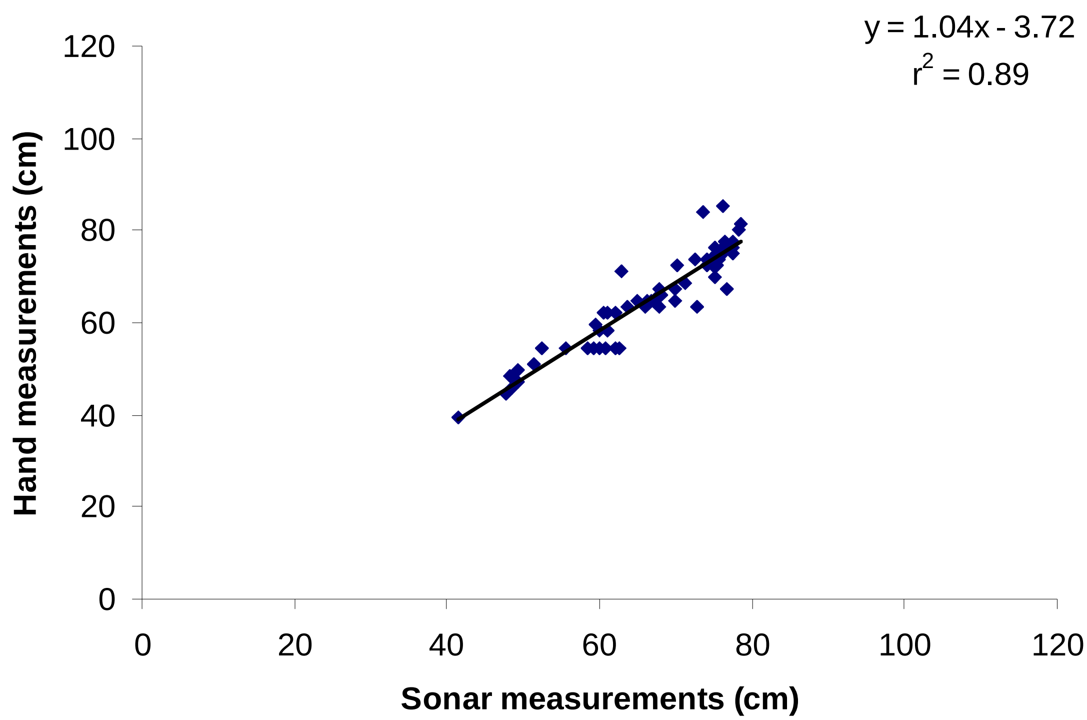

Figure 14. Relationship between measured plant height and that estimated using sonar, 0 to 67 days after planting in cotton in 2006 at growth stage 7.

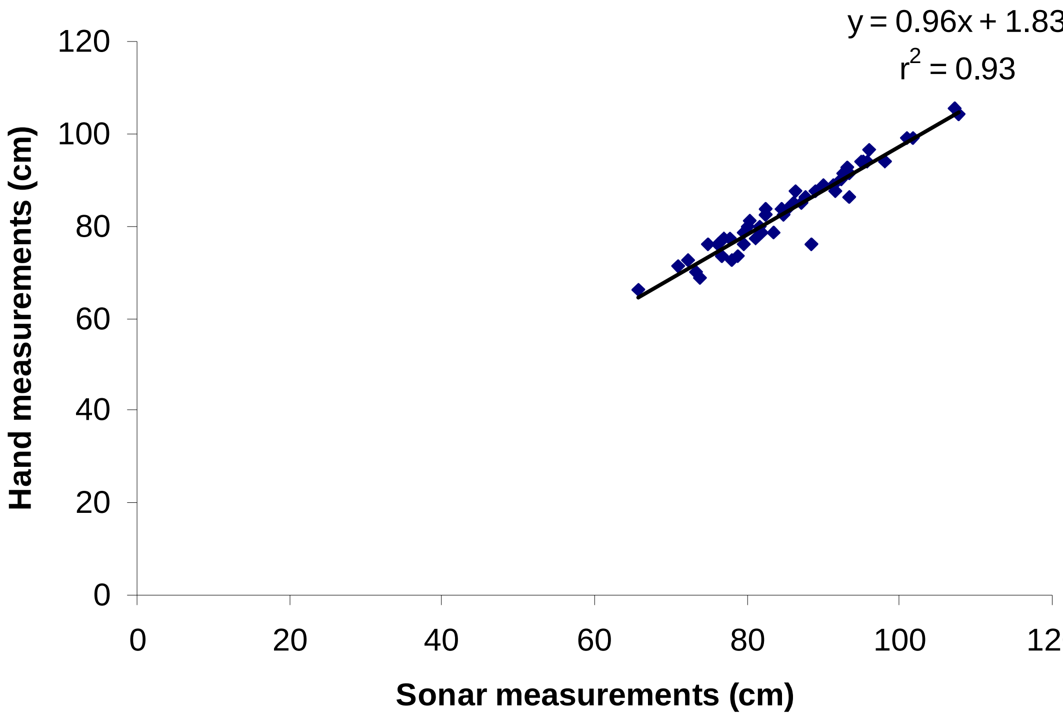

Figure 15. Relationship between measured plant height and that measured using sonar, 0 to 73 days after planting in cotton in 2006 at growth stage 7.

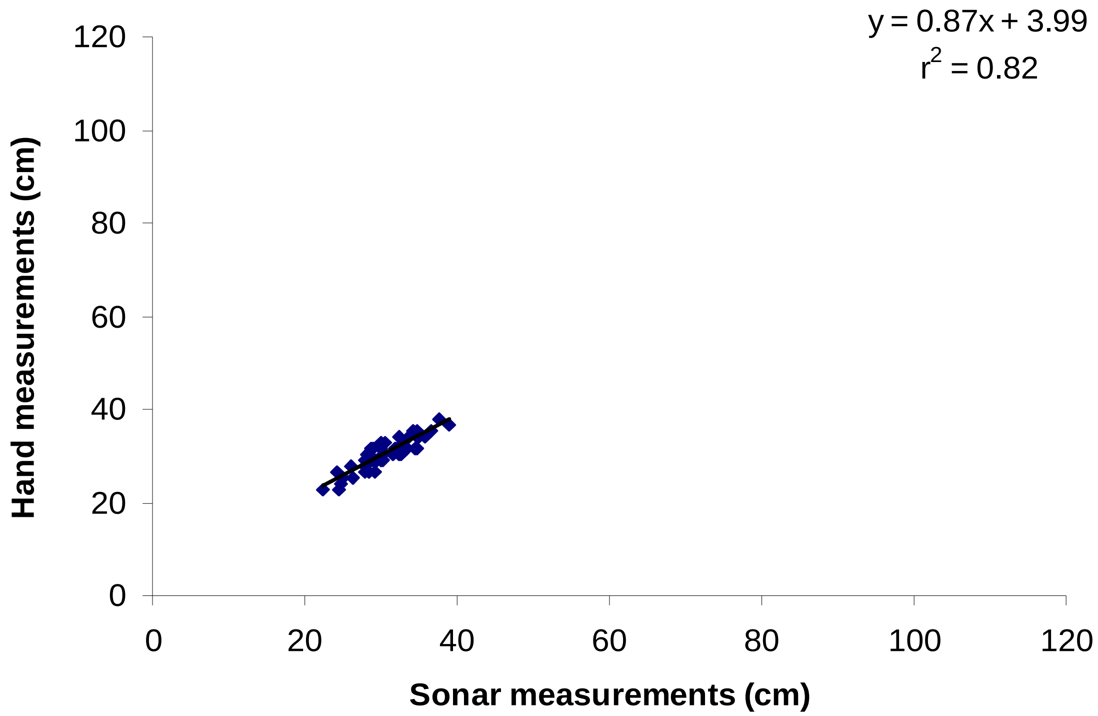

Figure 16. Relationship between measured plant height and that estimated using sonar, 0 to 35 days after planting in cotton in 2007 at growth stage 1.

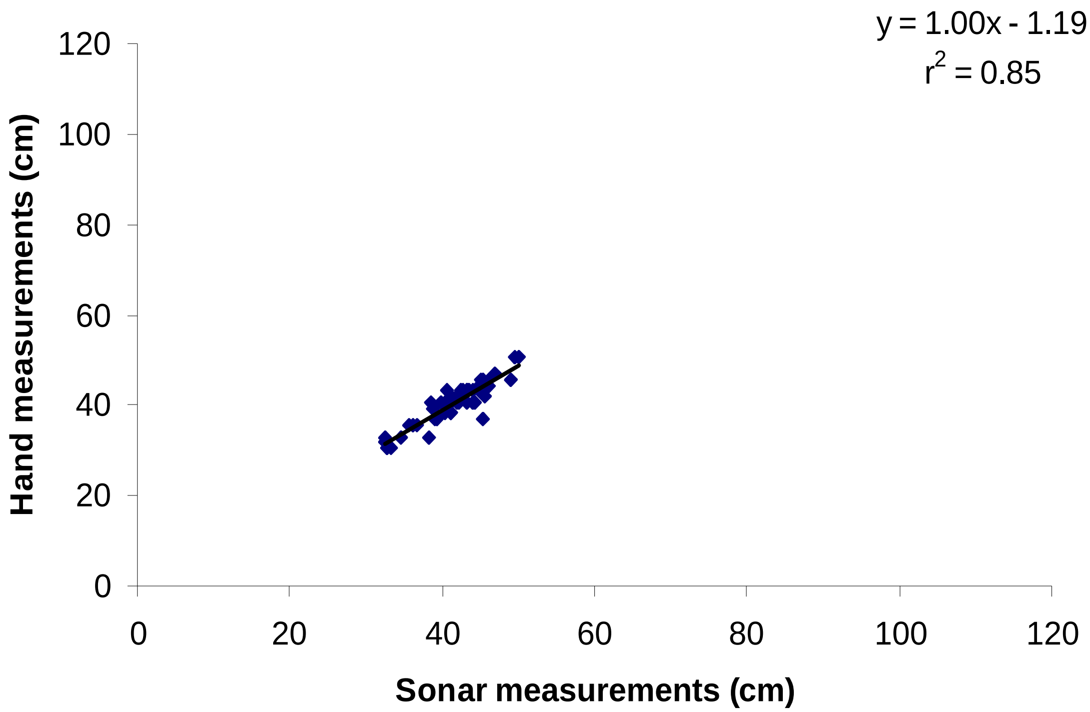

Figure 17. Relationship between measured plant height and that estimated using sonar, 0 to 55 days after planting in cotton in 2007 at growth stage 3.

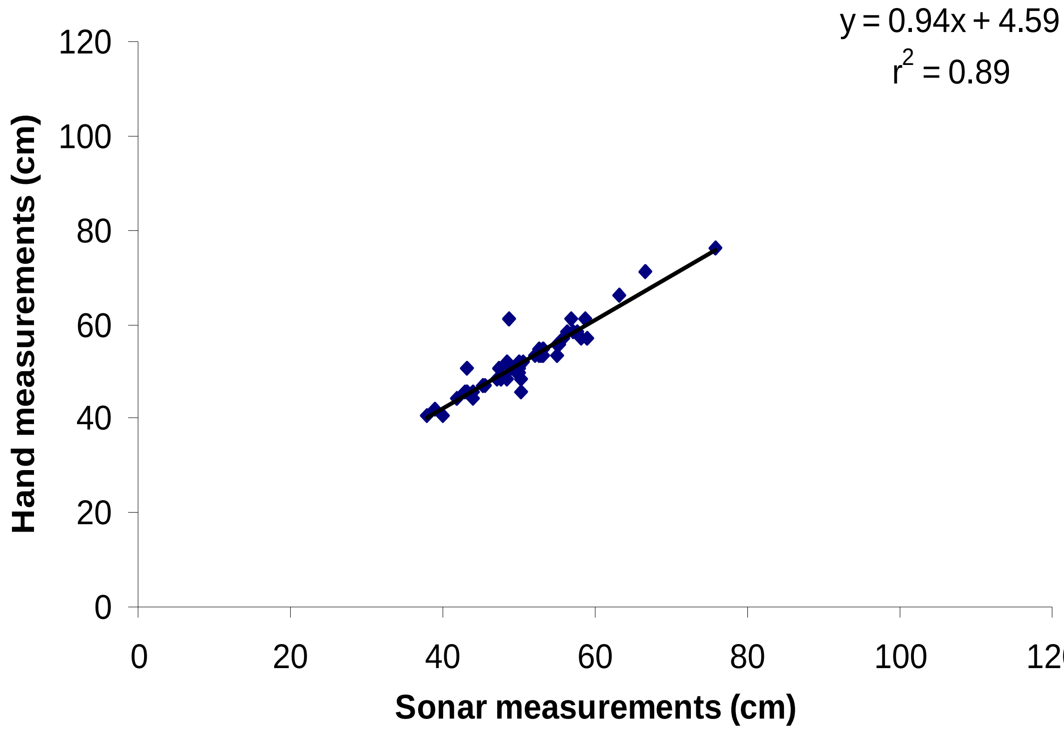

Figure 18. Relationship between measured plant height and that estimated using sonar, 0 to 62 days after planting in cotton in 2007 at growth stage 5.

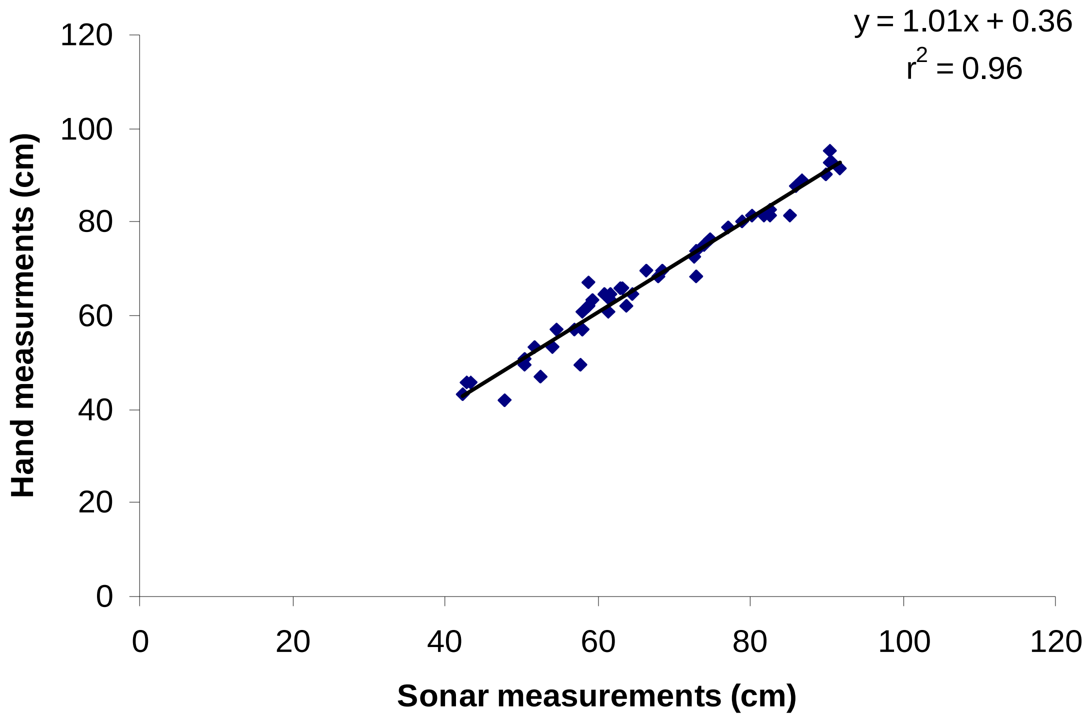

Figure 19. Relationship between measured plant height and that estimated using sonar, 0 to 69 days after planting in cotton in 2007 at growth stage 5.

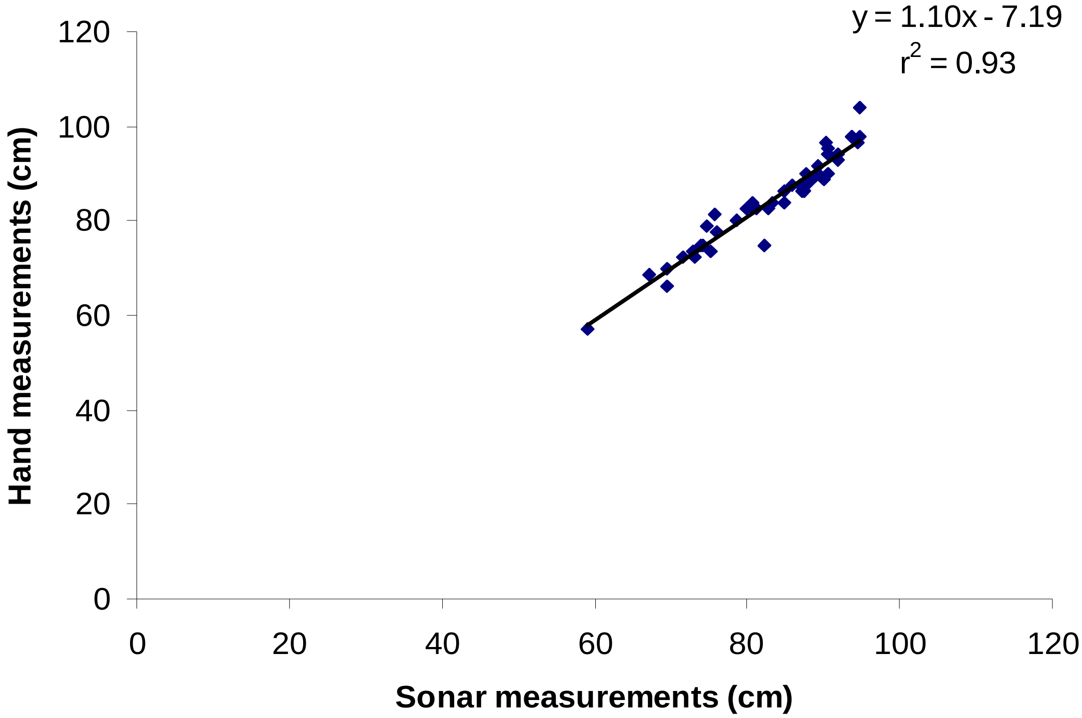

Figure 20. Relationship between measured plant height and that estimated using sonar, 0 to 82 days after planting in cotton in 2007 at growth stage 7.

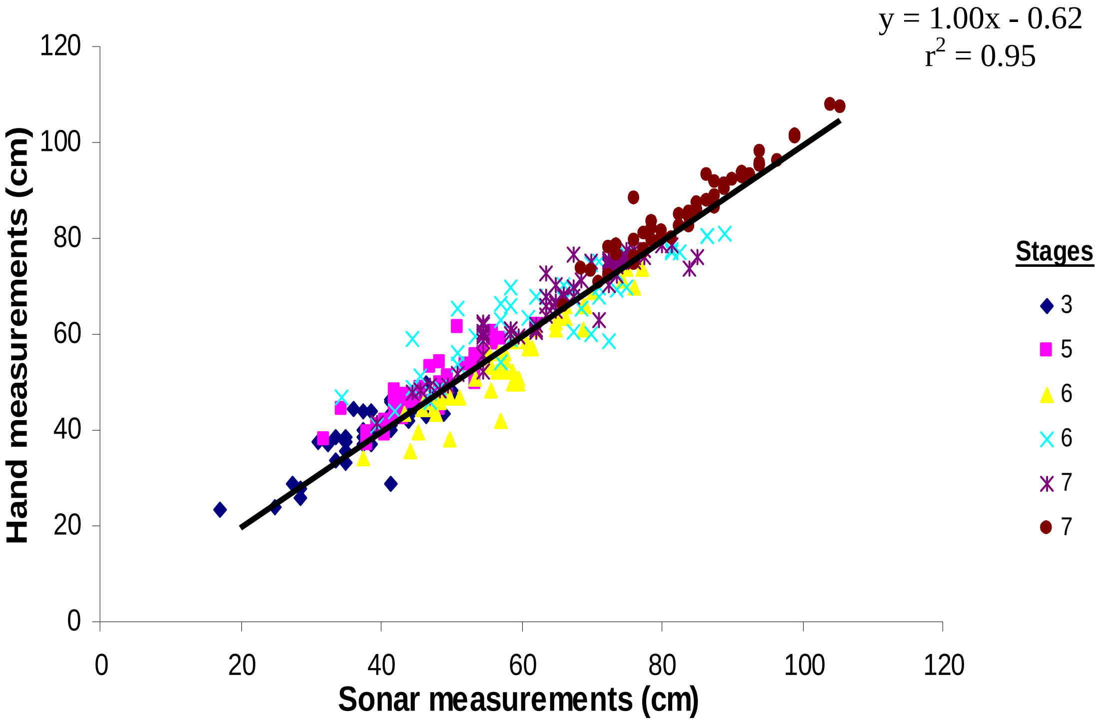

Figure 21. Relationship between measured plant height and that estimated using sonar, 0 to 73 days after planting in cotton in 2006 for all growth stages in 2006.

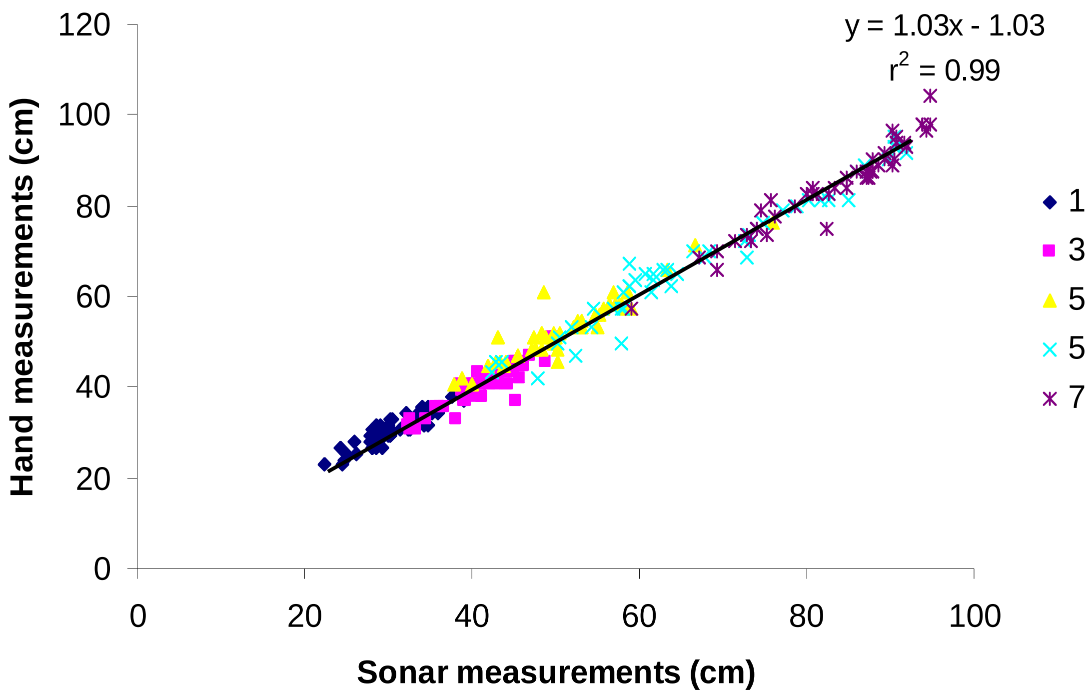

Figure 22. Relationship between measured plant height and that estimated using sonar, 0 to 82 days after planting in cotton in 2007 all growth stages 2007.

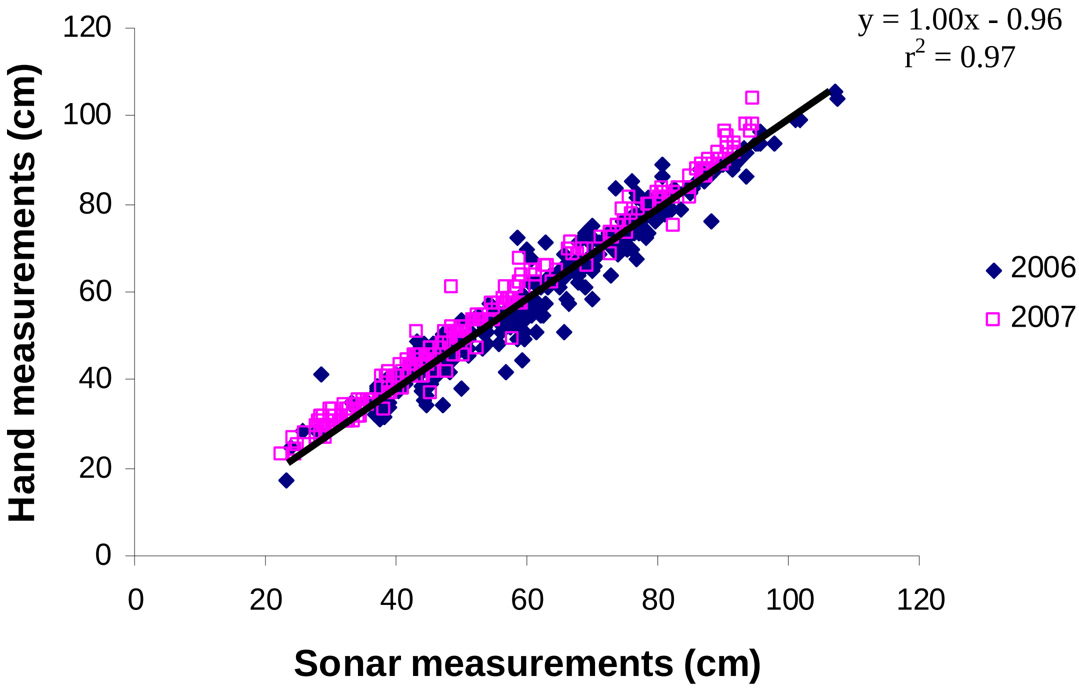

Figure 23. Relationship between measured plant height and that estimated using sonar, 0 to 82 days after planting in cotton for all 2006 and 2007 growth stages.

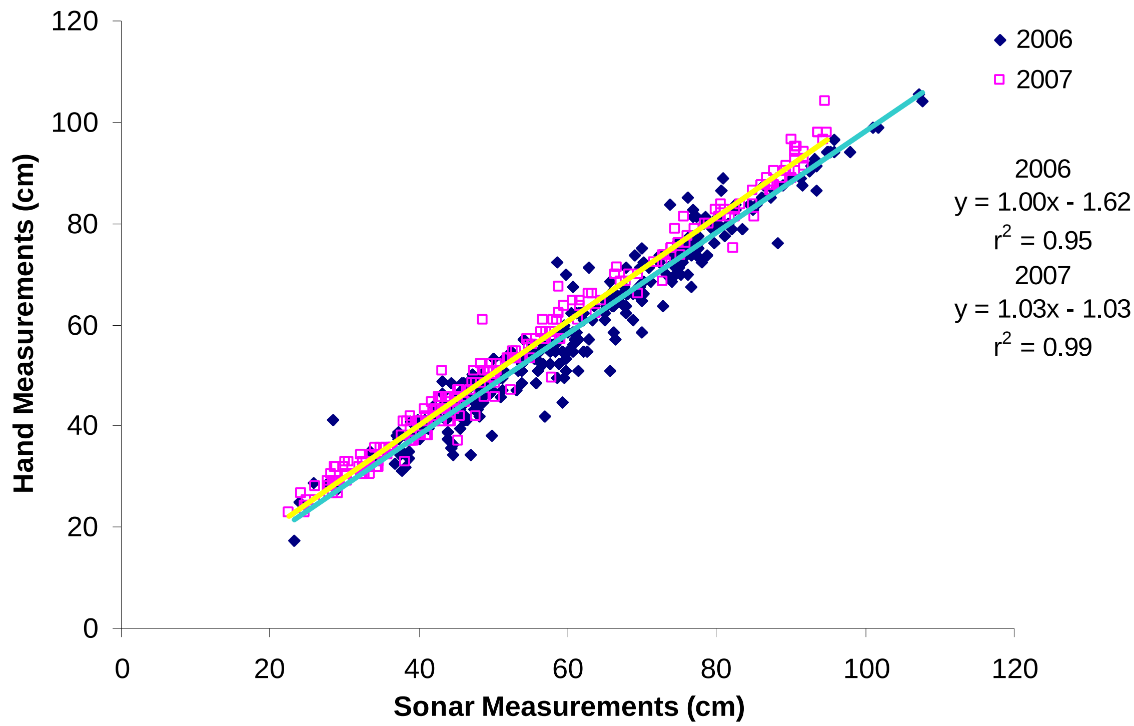

Figure 24. Combined data and linear regression trend line for cotton 2006 and 2007.

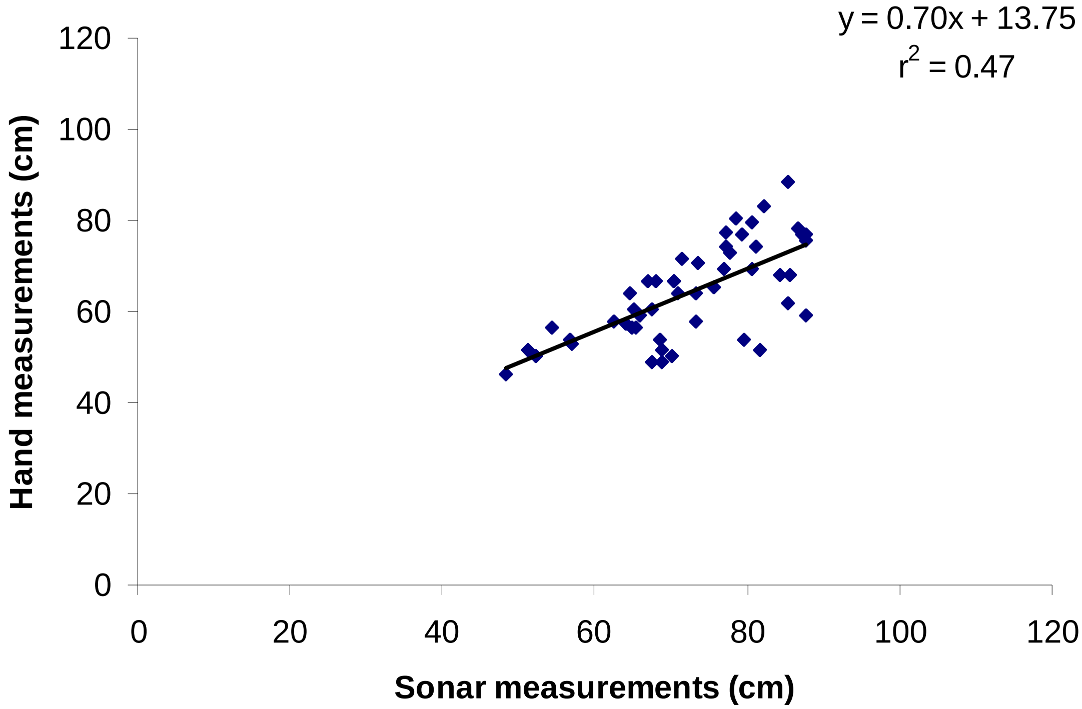

Figure 25. Relationship between measured plant height and that estimated using sonar, 0 to 43 days after planting in sorghum in 2006 at growth stage 3.

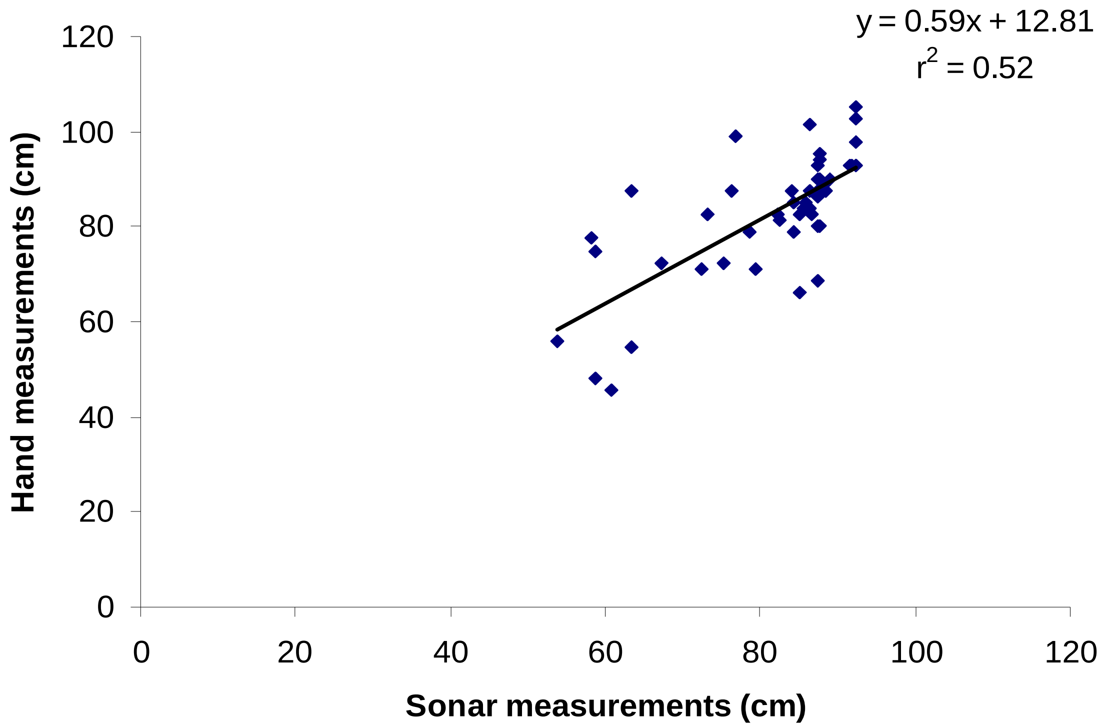

Figure 26. Relationship between measured plant height and that estimated using sonar, 0 to 53 days after planting in sorghum in 2006 at growth stage 4.

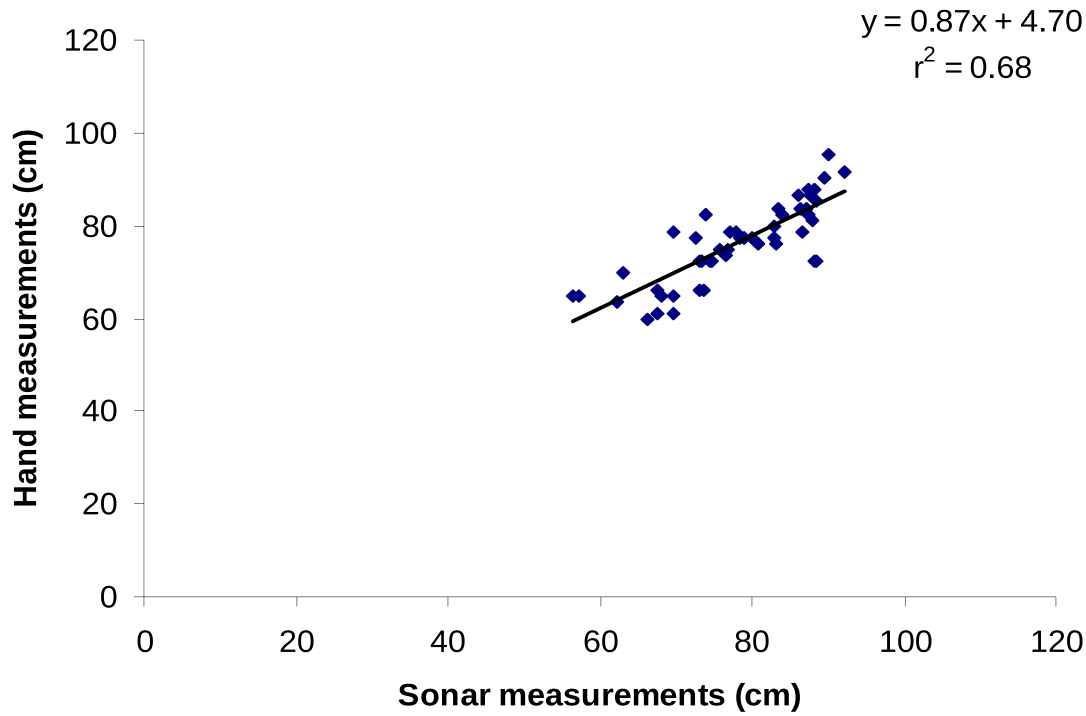

Figure 27. Relationship between measured plant height and that estimated using sonar, 0 to 60 days after planting in sorghum in 2006 at growth stage 5.

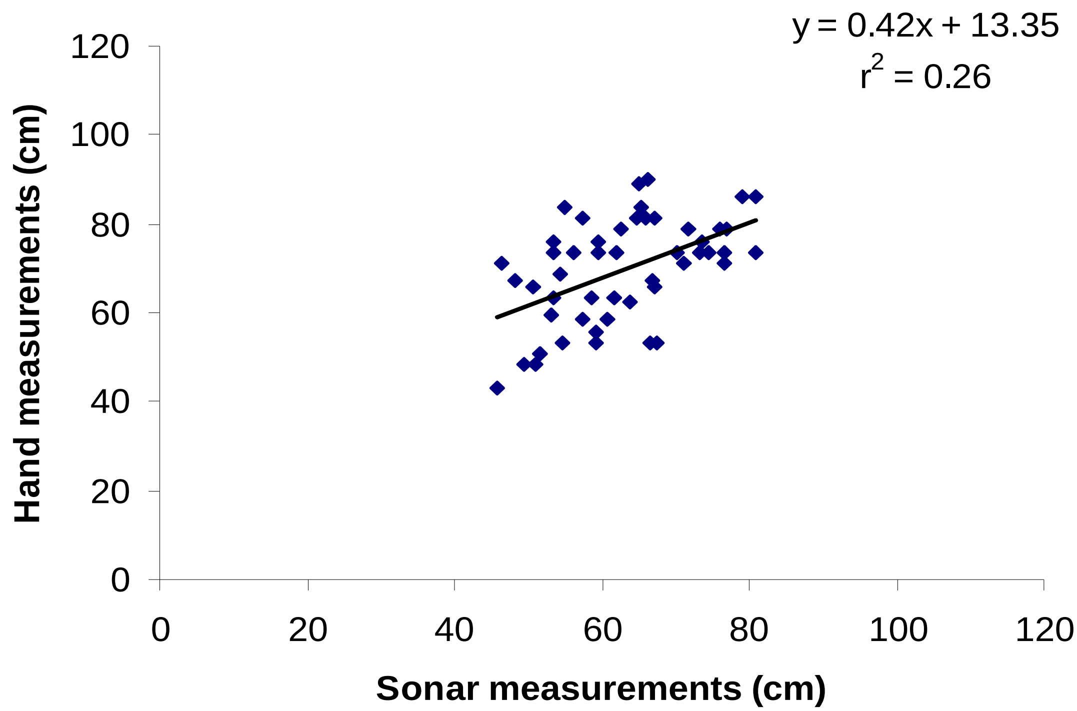

Figure 28. Relationship between measured plant height and that estimated using sonar, 0 to 64 days after planting in sorghum in 2006 at growth stage 6.

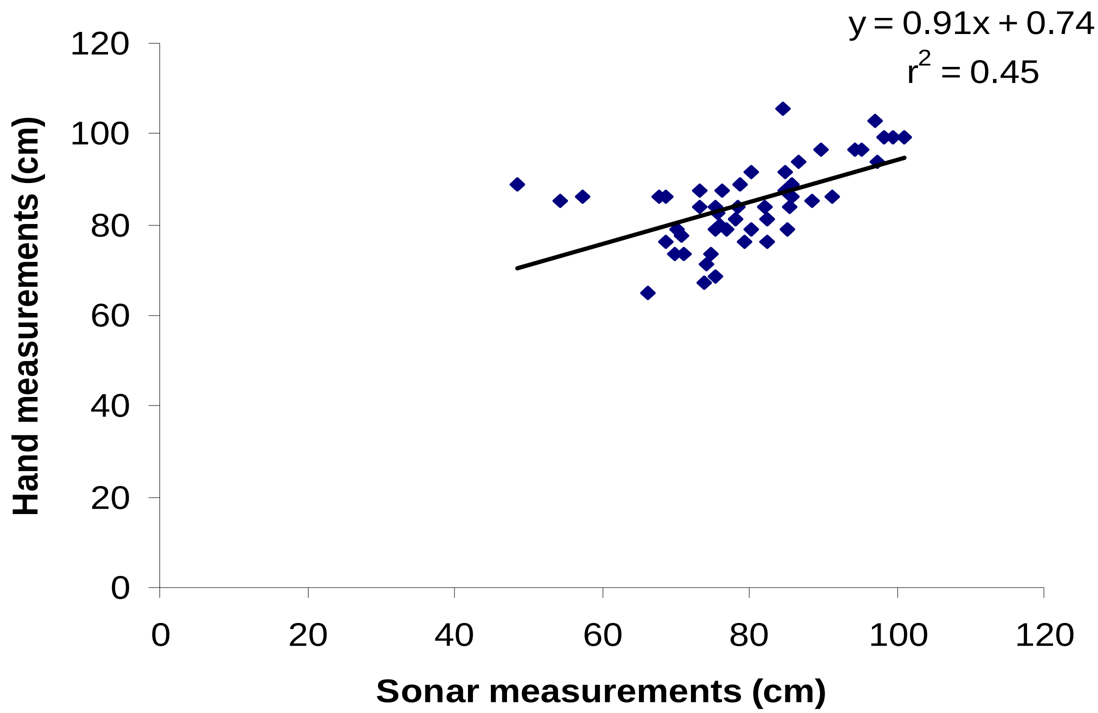

Figure 29. Relationship between measured plant height and that estimated using sonar, 0 to 67 days after planting in sorghum in 2006 at growth stage 7.

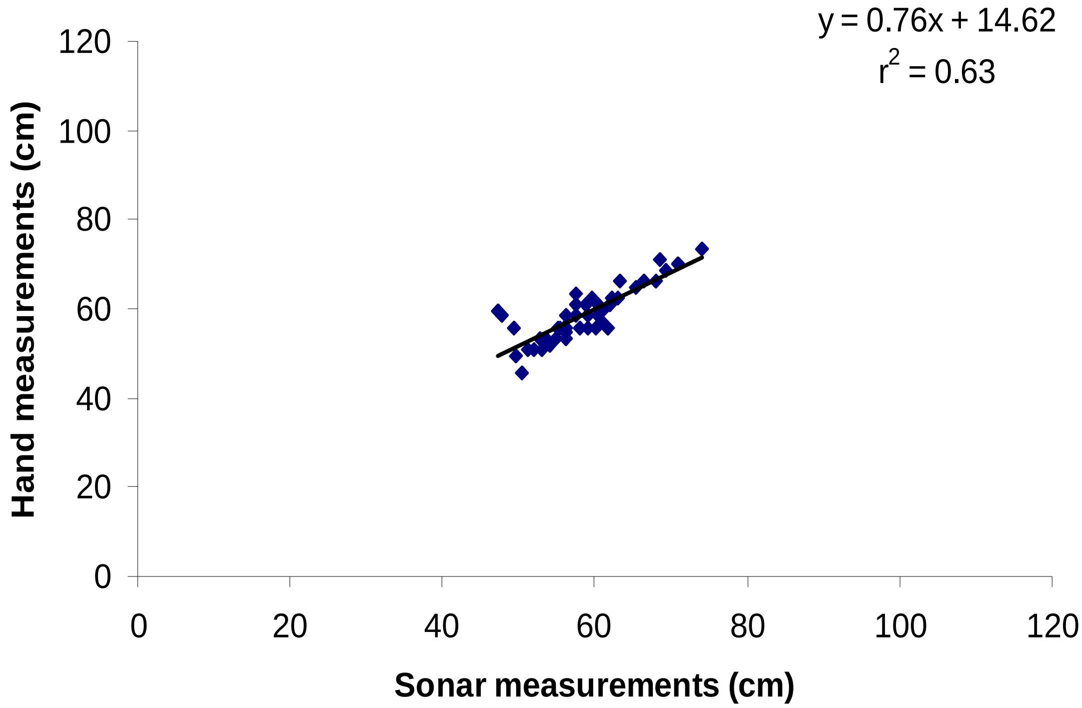

Figure 30. Relationship between measured plant height and that estimated using sonar, 0 to 34 days after planting in sorghum in 2007 at growth stage 3.

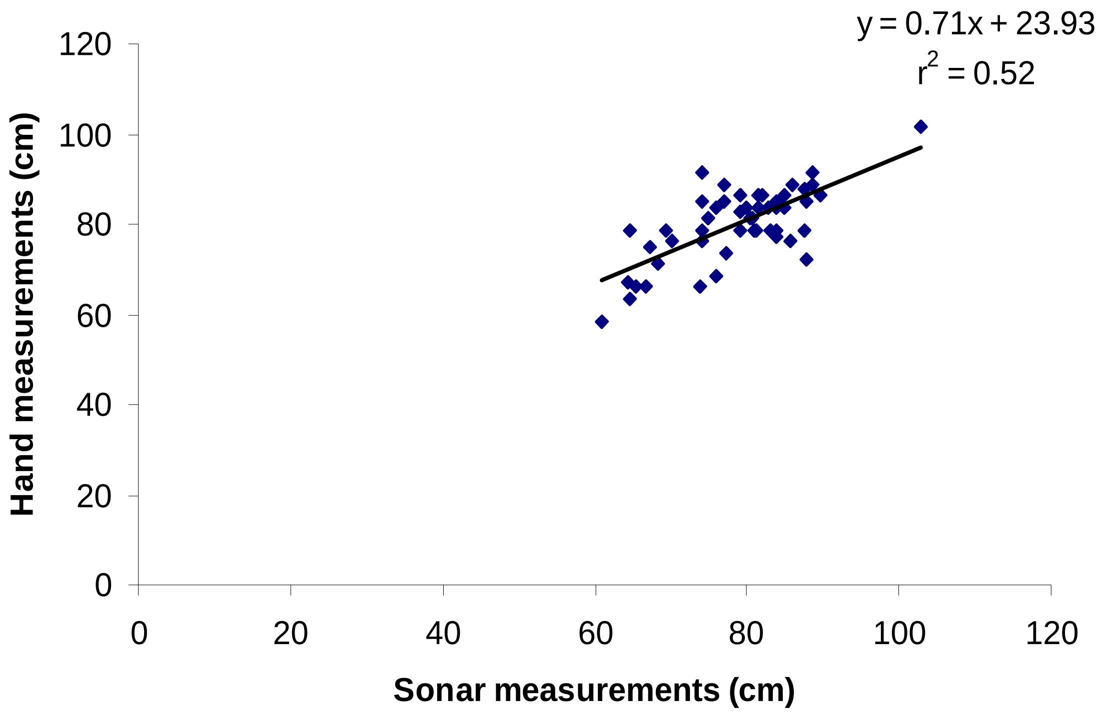

Figure 31. Relationship between measured plant height and that estimated using sonar, 0 to 54 days after planting in sorghum in 2007 at growth stage 5.

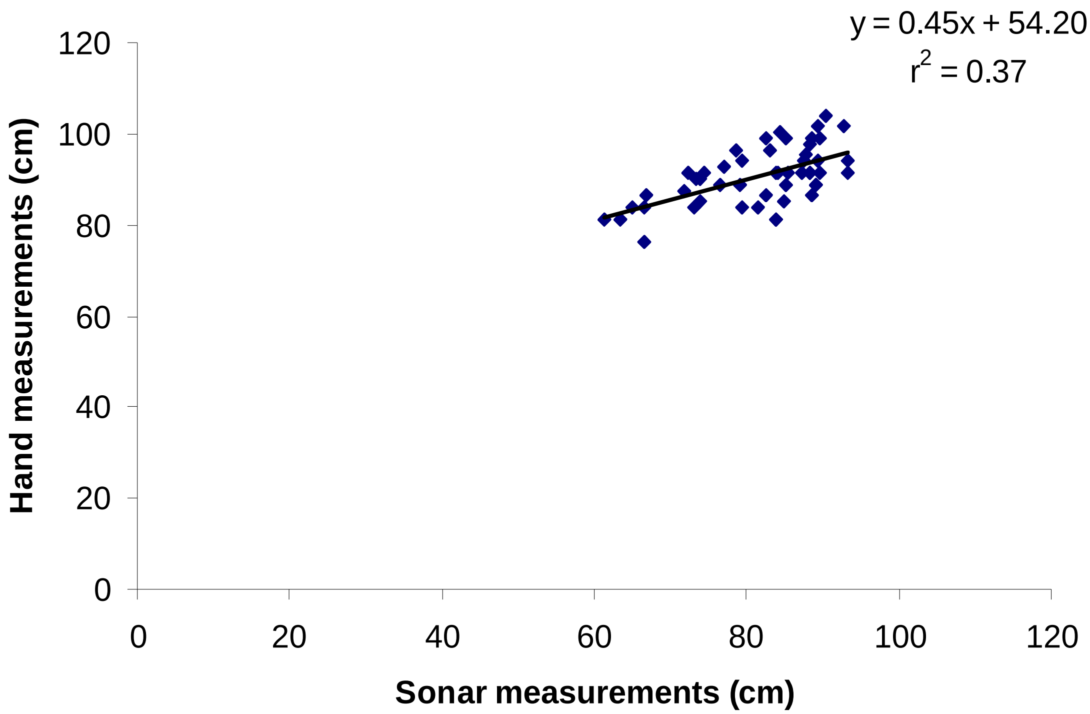

Figure 32. Relationship between measured plant height and that estimated using sonar, 0 to 62 days after planting in sorghum in 2007 at growth stage 5-6.

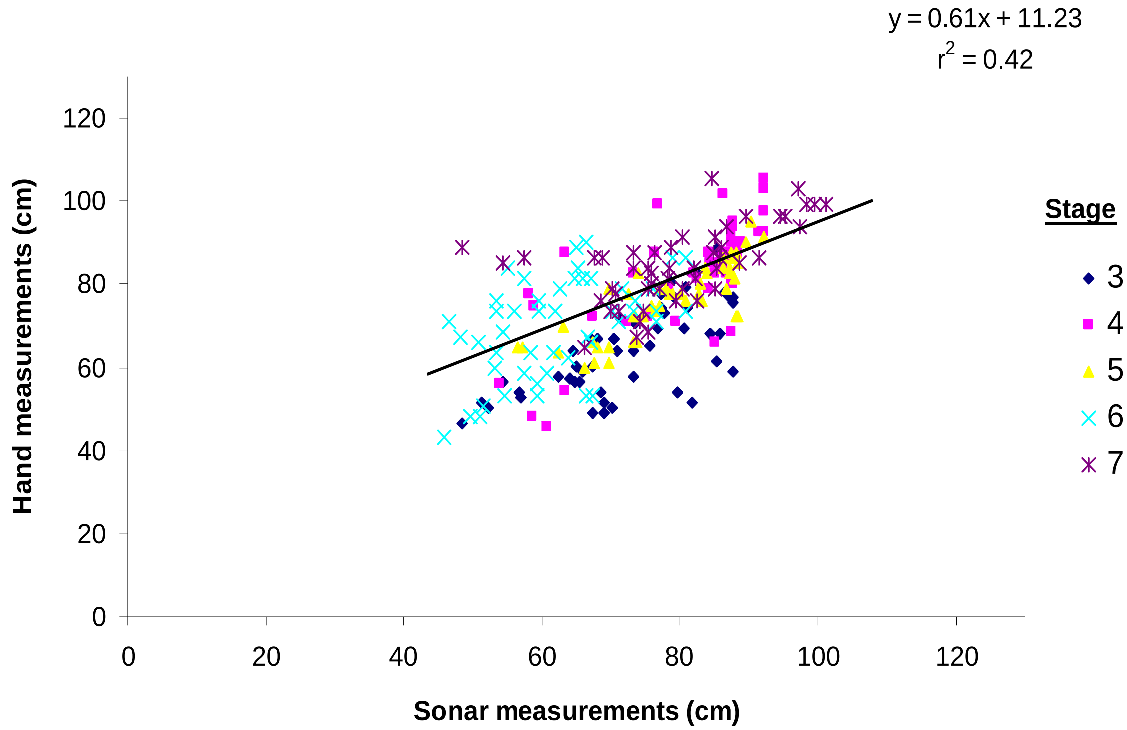

Figure 33. Relationship between measured plant height and that estimated using sonar, 0 to 67 days after planting in sorghum in 2006 including all growth stages.

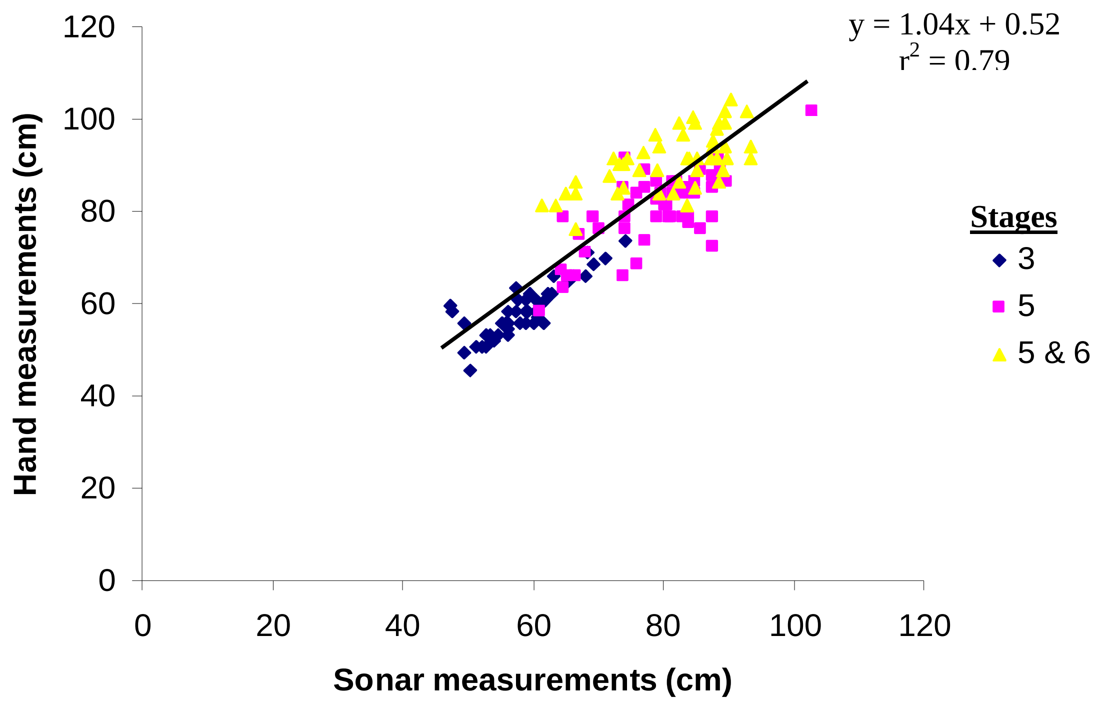

Figure 34. Relationship between measured plant height and that estimated using sonar, 0 to 62 days after planting in sorghum in 2007 including all growth stages.

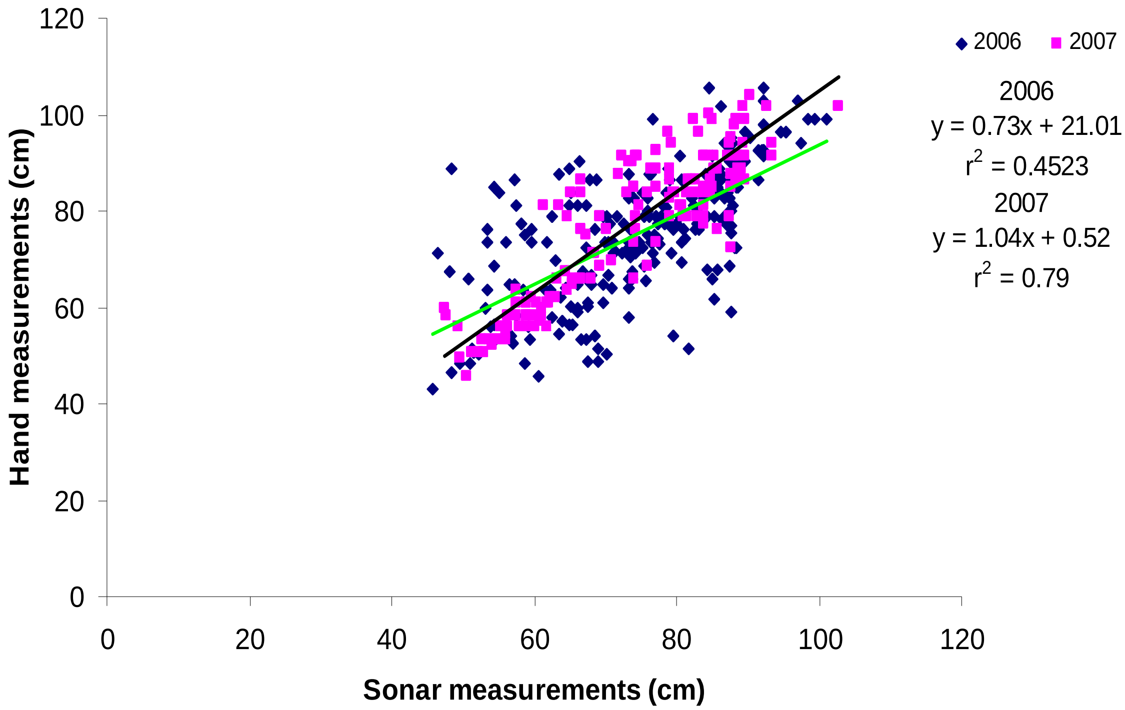

Figure 35. Combined data and linear regression trend line for sorghum 2006 and 2007.

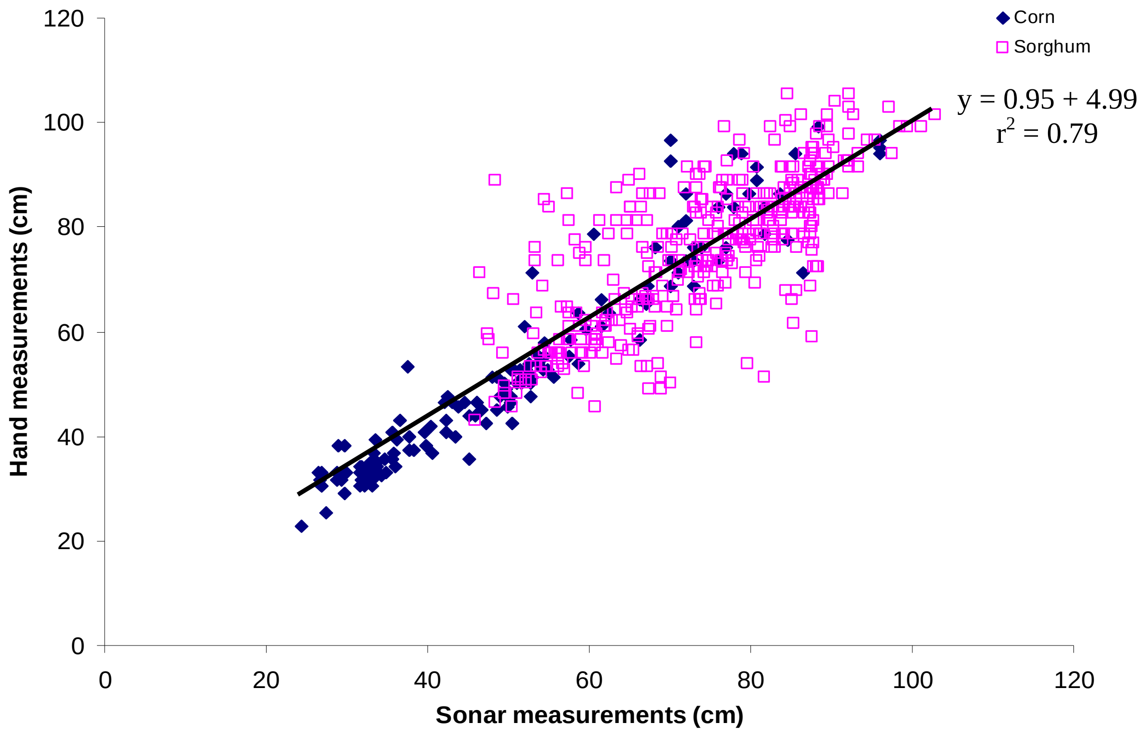

Figure 36. Combined data and linear regression trend line for corn and sorghum 2007.

APPENDIX

Location	Soil Series
Lake Carl Blackwell	Port; (fine-silty, 0 to 1 percent slopes, occasionally flooded)
Perkins	Teller; (fine sandy loam, 3 to 8 percent slopes, eroded)
Agronomy Farm (Teaching Demo and 222)	Kirkland (silt loam, 1 to 3 percent slopes)

Table 1. Soil series classification and description for all experimental sites in 2006-2007.

Location	Crop	Year	Planting Date	Variety	Seeding Rate
Lake Carl Blackwell	Cotton	2006	5-15-06	Monsanto NG3273B2RF	52,000 plants/ac
		2007	5-17-07	Stoneville ST6611B2RF	52,000 plants/ac
Lake Carl Blackwell	Sorghum	2006	5-16-06	DEKALB DKS 44-41	50,000 plants/ac
		2007	5-17-07	Asgrow-Pulsar	80,000 plants/ac
Perkins	Corn	2007	5-16-07	DEKALB DKC 50-20	17,500 plants/ac
Lake Carl Blackwell		2007	4-6-07	DEKALB DKC 66-23	31,700 plants/ac
Teaching Demo	Wheat	2007	9-14-06	Fanin	80 lb/ac
Stillwater 222		2007	10-3-06	Endurance	85 lb/ac

Table 2. Location, crop type, year, planting date, variety, and seeding rate for all experimental sites in 2006-2007.

VITA

Pamela Lynn Turner

Candidate for the Degree of

Master of Science

Thesis: INDIRECT MEASUREMENT OF CROP PLANT HEIGHT

Major Field: Plant and Soil Sciences

Biographical:

Personal Data: Born in Joplin, Missouri, on September 30, 1983

Education: Completed the requirements for the Master of Science degree with a major in Plant and Soil Sciences at Oklahoma State University, Stillwater, Oklahoma in May, 2008.

Experience: Employed by Plant and Soil Sciences Soil Fertility Project from 2004 to 2006; employed by Oklahoma State University, Department of Plant and Soil Sciences as a graduate student, 2006 to present.

Professional Memberships: Golden Key International Honor Society (2007 - 2008), Gamma Sigma Delta Honor Society of Agriculture (2007 - 2008) Soil and Water Conservation Society Oklahoma State University Chapter, Agronomy Club Oklahoma State University Chapter (2005-2006), Professional Soil Science Association of Oklahoma (2006), American Society of Agronomy (2005 – 2007), Crop Science Society of America (2005 - 2007), Soil Science Society of America (2005 - 2007), Soil and Water Conservation Society (2005 - 2007)

Name: Pamela Lynn Turner Date of Degree: May, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INDIRECT MEASUREMENT OF CROP PLANT HEIGHT

Pages in Study: 55 Candidate for the Degree of Master of Science

Major Field: Soil Science

Scope and Method of Study: Establish the relationship between hand and sonar measurements is essential to include plant height in “on the go” predictions of forage biomass and N fertilizer rate requirements

Findings and Conclusions: Although expressed variation is know throughout agriculture fields, methods are being developed to account for this in-field variability. This study developed a method of determining height accurately for cotton (all growth stages), corn (early growth stages), and wheat (early growth stages). Although sorghum was also studied, due to morphological characteristics of the crop’s canopy, sorghum’s height was difficult to determine accurately.

ADVISER’S APPROVAL: Dr. William Raun